ANALYSIS OF ENERGY USE IN TYPICAL GREEK RESIDENTIAL BUILDINGS AND PROPOSED RETROFIT STRATEGIES

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ANALYSIS OF ENERGY USE IN TYPICAL GREEK RESIDENTIAL BUILDINGS AND PROPOSED RETROFIT STRATEGIES

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LIST OF SYMBOLS AND ABBREVIATIONS

Δ.E.H	Public Power Corporation
EL.STAT	Hellenic Statistical Authority
TIR	Thermal Insulation Regulation
EMY	Hellenic National Meteorological Service
HVAC	Heating Ventilation and Air Conditioning
ASHRAE	American Society of Heating Refrigerating and Air Conditioning
DSWHS	Domestic Solar Water Heating System
EU	European Union
COP	Coefficient of Performance
EPBD	Energy Performance Building Directive
ECCP	European Climate Change Program
CO_2	Carbon Dioxide
CA	Concerned Action
KENAK	Building Energy Regulation Improvement
YPEKA	Ministry of Environment, Energy and Climate Change
TEE	Technical Chamber of Greece
TOTEE	Technical Handbook, Technical Chamber of Greece
TEE KENAK	Greek Rating Simulation Software
NOA	National Observatory of Athens
ELOT	Hellenic Organism of Standardization
EN ISO	Standard
CA	Concerned Action

TMY	Typical Meteorological Year
EPC	Energy Performance Calculator

SUMMARY

In each country, the concept of housing exists in relationship between the ways people live, the local climate, the social and political factors that affect the evolution of architecture and the actual structure of the house. The economic developments of the countries and the political situations and regulations have all affected the rise of the residential market. In Greece, where the majority of the residential buildings were constructed between 1960 and 1990, residential buildings represent an important sector in the energy consumption and economic growth of the country.

Global warming and changes in the climate system has an important impact in building stock. The European Union is concerned about the scale of the consequences and has encouraged energy efficiency in buildings by mandating the Energy Performance Building Directive for all European countries [1].

In my opinion, it is the responsibility of the architect to address the impact of existing residential buildings by retrofitting solutions with the aim of reducing the energy consumption and eventually improving the quality of life. Architects, in collaboration with energy experts, can work properly to provide effective solutions. With the guidance of the new directive, along with their personal knowledge and experience in energy efficiency they can help bring about increased energy building performance.

In order to demonstrate how architects can implement such an energy retrofit plan, this thesis presents a short description of residential buildings constructed between 60's – 80'by presenting a typical building representing the current state of the Greek building stock, and by studying its energy consumption. An energy performance simulation of the building with different energy simulation software considers different scenarios and describes a way to reduce energy demand and increase comfort in these buildings. The primary software tools used in the study was TEE KENAK, developed by

the Greek chamber in accordance with the European energy rating tools for the implementation of the Energy Performance Building Directive. Additional software tools, including ECOtect, and the "Energy Performance Calculator", developed by the department of High Performance Buildings at the Georgia Institute of Technology in order to verify the information provided by the actual energy bills and the TEE KENAK. The results presented in this study estimate the building retrofit and energy saving, making appropriate decisions in terms of energy conservation and improvement in the existing residential building considering energy cost savings, payback from retrofit investments, along with architectural design considerations.

1. INTRODUCTION

In most developing countries the energy usage in the residential sector accounts for a significant percentage of the total energy consumption. During the last decades residential energy usage is in constant growth. Income levels, natural resources, climate change and the available energy mix are the key factors that affect the energy usage by household in a given country [2].

The majority of Greek cities are characterized by the post-war urbanization and have been developed with apartment building blocks known as “polykatoikia” [3]. This type of buildings became the city's urban characteristic and now constitute the predominate local architecture of a contemporary Greek city.

Typical building apartments are usually four stories, while they occasionally exceed six stories high and follow a regular shape and a restrictive lack of architecture expression. The apartment buildings are commonly built by private companies, on individually family owned restricted lots. One or more apartments are located in each floor depending on the size of the building. Usually the apartments are occupied by the family that owns the building [4-6]. Most of these buildings were constructed under the same building regulations. The building plan is designed to achieve the maximum allowable heights and maximum light penetration. Architectural features commonly found on these buildings include balconies along the facade, “piloti” that raise the building to accommodate parking, a flat roof, a central vertical staircase in the core of the building, and light wells to bring light into the lower floors.

Horizontal circulation is regulated through a long corridor serves the different zones. The apartment can be divided in two parts. The common areas such as the living room face the urban edge of the city, and the more private spaces such as the bedrooms, usually face a private open space. A common characteristic is the subdivision of the apartment in different zones with vertical wall elements. Each zone is isolated and the central corridor is the only way of connection between these elements. This characteristic can be related to the need of thermal comfort control, privacy and odors.

According to the Hellenic Statistical Authority (EL.STAT)[7], buildings constructed before 1980 represent the 74.6% of the building stock in Greece and are classified in the first category of the building stock that represents buildings with no thermal insulation protection. The second category consists of dwellings constructed during the period 1980-2001 which in the majority are partially insulated. The third category includes the buildings that were constructed from 2001 up to year 2011. Only the buildings that belong to the last category are well insulated with no thermal bridges and with double glazed windows. In addition, the residential building stock is subdivided into two categories classified by the number of floors. Single Dwellings, for low-rise buildings (one to two floors) and apartment buildings, for high-rise building (more than two floors) [7, 8]. This study and its findings focus on the larger buildings, which are typically occupied by the building owner and family in separate apartments.

Energy consumption in these Greek residential buildings is among the greatest energy consuming sectors [9-13]. The national energy balance data, available from the Hellenic Ministry of Development report the percentage of energy consumption during the past 40 years. Residential dwellings represent 25% of the total energy consumption of the Hellenic building stock and consume 32.7% of the total electricity produced in Greece. They consume 21.5% of the total energy [8, 14].

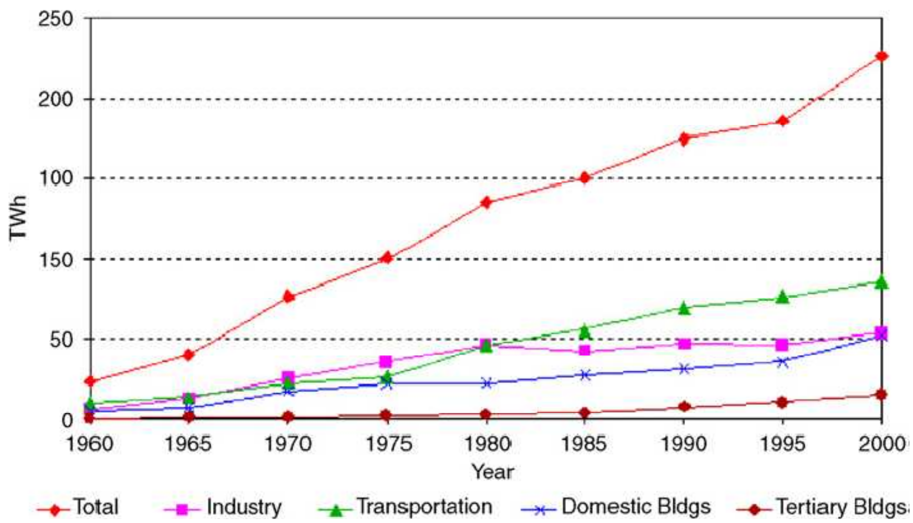


Figure 1: Energy demand by sector in Greece[14]

In order to examine the energy efficiency of multi-generational single-family homes in Greece, a four story building with basement and a flat roof was chosen as a representative single-family house type building. This building, located in the city of Heraklion in Crete is shown in Figure 2.

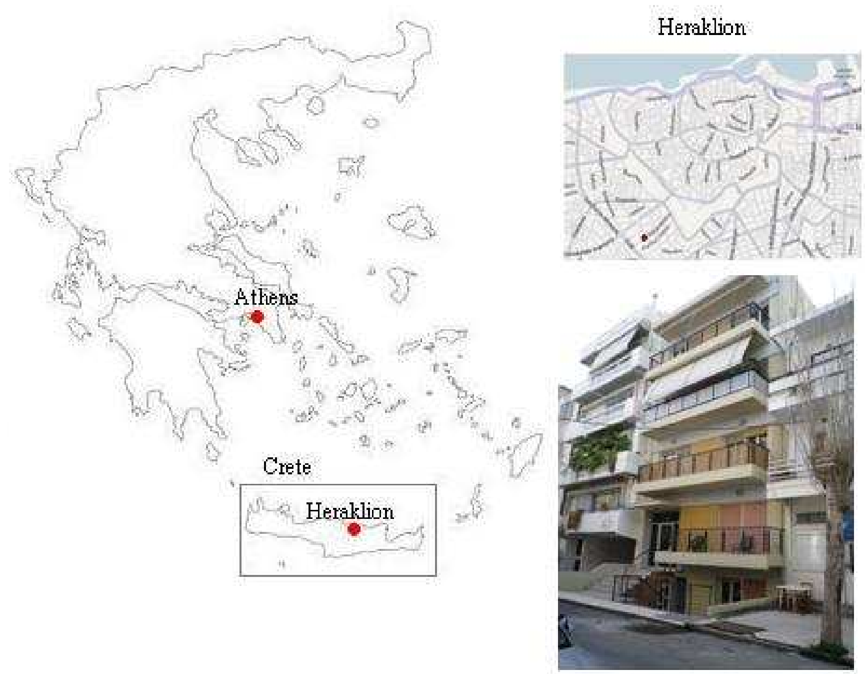


Figure 2: Building, location

The average age of these buildings is close to thirty years. The description on the existing conditions of this representative building is based on information about the location, surrounding, environment, envelope shading, ventilation, domestic hot water, as well as details regarding the energy consumption behavior of the building. Information about location surrounds, design and structural characteristics of the building are derived from the experience of the author who is trained as an architect and is quite familiar with the design and construction of these buildings. Information about energy consumption (electricity, fuel and water) rely on energy bills, and data provided by Public Power Corporation (Δ.Ε.Η) [15] as well as the Hellenic Statistical Authority (EL.STAT) [7]. The methods and the techniques used in the construction of the building are influenced by many factors such as the climatic conditions the building materials, Greek traditions and the social and economical background.

Our case-study building is not thermally insulated, since the building was constructed before the application of the national Thermal Insulation Regulation (TIR) that sets the minimum requirements of thermal insulation for the building envelope for different climatic zones [8, 16, 17] . The climatic zones are categorized in Zone A, Zone B, Zone and C. Crete belongs to the Zone A. According to the European Union directives, in1993 a few additional laws were introduced in Greece to curtail energy usage, such as the annual maintenance of central heating boilers and policies for the annual gas analysis and inspection of boilers and electrical devices[16]

Figure 3: Climatic zones according to the existing thermal insulation regulation of 1979 [36]

Table 1: Main climatic data for representative cities of the three climatic zones in Greece [18]

Location	Heating degree days for 18ºC	Cooling degree days for 25ºC	Design cooling conditions ºC	
			DB	WB
Heraklion (zone A)	782	225	32.5	24
Athens (zone B)	1100	245	34.5	25
Thessaloniki (zone C)	1725	169	34.5	24

2. THE TYPICAL GREEK RESIDENTIAL BUILDING

Design and structural parameters

The building consists of three floors, a ground floor and a basement. Each floor features an apartment. Communication between the floors is via a central stairwell which contains the elevator and the staircase. The building is adjacent to two adjacent residential buildings on the north-east and south-west side. The building plan is a simple rectangle; with its main facade, north- west oriented, and a small backyard (63 m²) on the south-east side. The two free elevations are occupied by continuous balconies on three levels that are characteristic of the Greek style. Balconies vary in the width of 1,4m to 0,65m. A secondary balcony, with a floor area of 0.72 m², is located in the kitchen.

In the basement there are four small studio-apartments and a small mechanical room that contains the boiler and other utilities. The surface of each studio-apartment is between 14.3m² to 23.3 m² and is served by a small kitchen and a bathroom. One studio-apartment is facing the main street Stergiogianni, one faces the light well, and two face the backyard. The floor area of the apartment on ground floor is 96 m², the remaining floor area, 22.5 m², is occupied by the stairs, the elevator and the main entrance. The surface of the first, second and third floor apartments is 120 m² .Each apartment includes a living room, 36.5 m² facing on north-west, main facade, a kitchen 10.2 m², a bathroom 6.1 2 m², a W.C 1,1 m², two bedrooms, 11.7 m² and 13 m² and an office room 5.7 m².

The terrace roof of the building where the water tanks, the solar water heater collectors and the television aerial installations are located is accessible to all occupants from the central staircase and the elevator.

Table 2: Keynotes to building plans

Be.R	Bedroom
Ba.R	Bathroom
K	Kitchen
LR	living Room
LW	Light Well
WC	WC

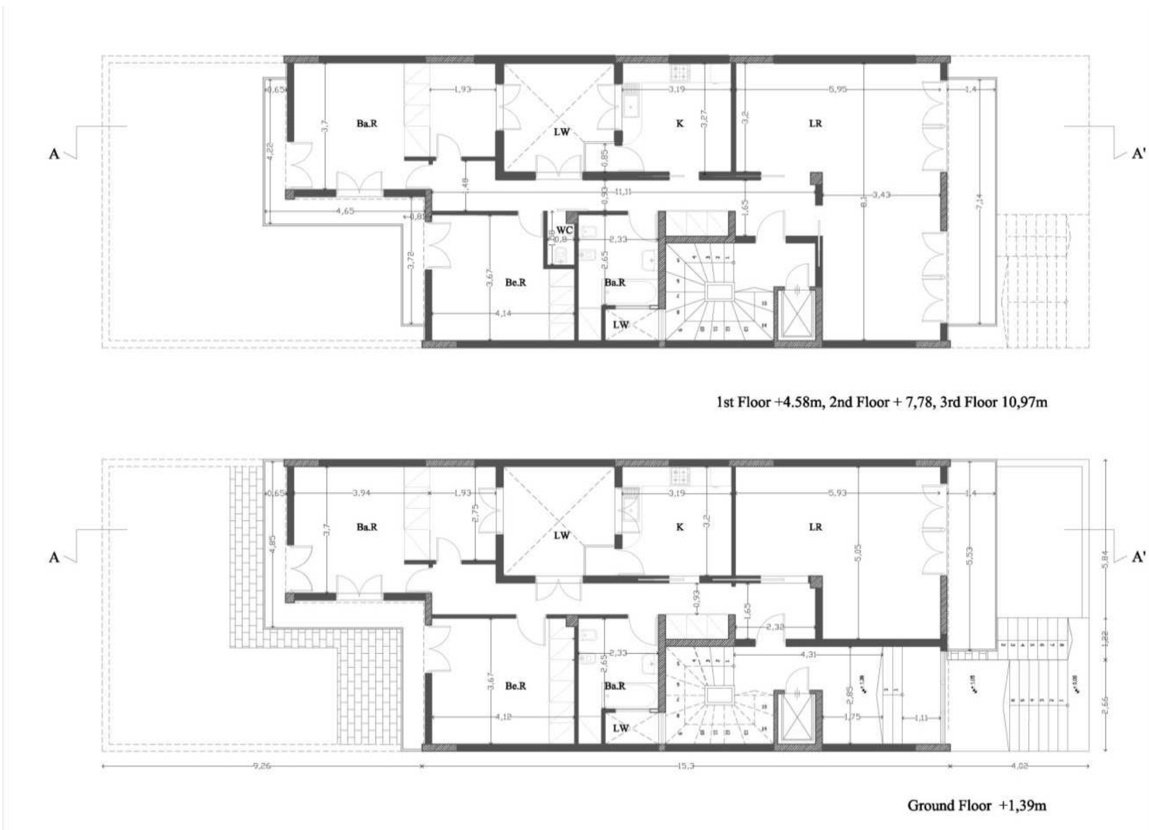


Figure 4: Basement, ground floor, 1^{st}-3^{rd} floor plans

Figure 4: Continued

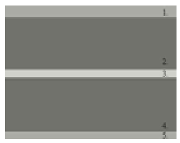
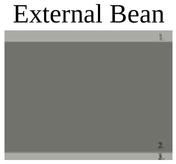
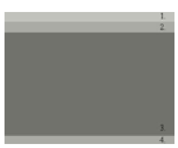
Description of construction

The exterior construction consists of load-bearing cavity walls 0.2 m thick. The double wall consists of paint, plaster 0.01m in the interior, 0.02m in the exterior plus two layers of bricks of 0.08m thickness. The calculated U-value for the assembly is 0.786(W/m²-k). The central wall columns consist of paint; plaster 0.01m and concrete 0.17m. The exterior parts of the columns are covered with ceramic tiles of 0.02m. The non-insulated roof consists of terrazzo tiles 0.02m in the exterior part, plaster coating 0,04m plaster coating and concrete slab 0.20m. See Table: 2.

Significant heat transfer occurs through the high percentage of non-insulated exposed beam and columns in the external envelope, indicating that insulation of exterior walls should be of a prime concern. The detailed drawing (see in Figure 4) represents typical configuration of buildings constructed before the introduction of Thermal Insulation Regulation (TIR) in Greece in 1979.

The analysis of the facade in figure 7 and 8 would help to study the impact of thermal bridges on the energy performance of the building as well as to examine the potentials of possible retrofitting measures. Heat loss through thermal bridges represents a significant percentage on the energy consumption, Figure 4.

Table 3: Wall and roof cross-section element proprieties

Element Cross section	**Layers**		**Attributes**
External brick Wall		Thickens (m)	
	1.Plaster	0.02	
	2.Brick	0.08	U-value
	3.Air Gap	0.01	(W/m²-k)
	4.Brick	0.08	0.687
	5.Plaster	0.01	
External Bean		Thickens (m)	
	1.Plaster	0.02	U-value
	2.Reniforsed Concrete	0.2	(W/m²-k)
	3.Plaster	0.01	3.209
External Structural wall		Thickens (m)	
	1.Plaster	0.02	U-value
	2.Reniforsed Concrete	0.17	(W/m²-k)
	3.Plaster	0.01	3.349
Flat Roof			
	1.Terrazzo	0.02	
	2.Cement Plaster	0.02	U-value
	3.Concrete Slab	0.2	(W/m²-k)
	4.Plaster	0.01	3.11

The thermal behavior of the construction materials in the main facades quantifies the overall energy performance of the building and highlights energy lost through thermal bridges. The openings represent the dominant component in the North-West facade of the building (37% of the total surface area), while the concrete slab (26%), beams and wall (17%) represent a lower but critical proportion of the facade's total surface. In the southeast facade the walls constitute the prime element (37% of the surface area).

External Openings

Every apartment has 3.08 m², operable fully-glazed door in each bedroom, facing south-east, a 1.40 m² window in the office, a 1.60 m² window in the corridor oriented in the south-west side, a 1.65 m² door and a 1.60 m² operable window in the kitchen, both facing the light well. The two 3.08 m² operable doors in the living room face north-west. One bedroom has a 1.40 m² window. Moreover, a small window 0.50 m² is located in the bathroom, facing a secondary light well. The door opening in the kitchen and the window frame in the bathroom are metal framed. The remaining window and door openings are wooden frame with single pane glazing. The internal doors of the apartments are constructed of wood and have a 2.2 m² surface area.

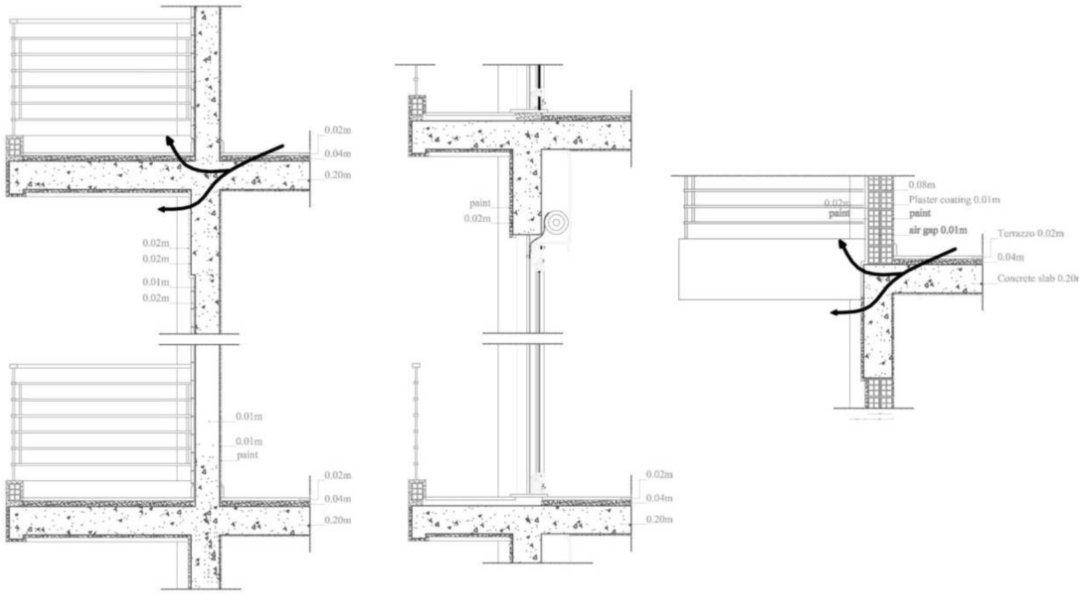


Figure 5: Architectural detail sections

Figure 6: Vertical section

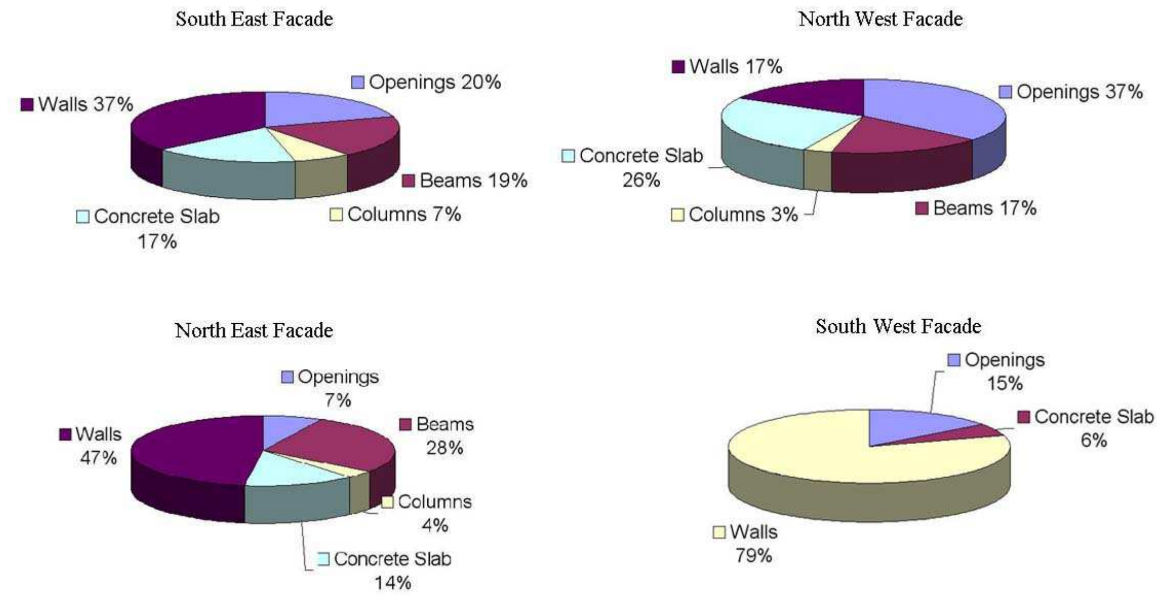


Figure 7: Percentage of construction elements in the facades

Figure 8: North-west façade, south-east façade

External shading is provided by wooden blinds which are rolled up into a case mounted on the top of every single opening and an awning in the north-west façade [19, 20] providing shading into the building and control of lighting and radiant heat gain for the interior space. The awing consists of a canvas material in which is incorporated a metal thin structure which is supported from the lower surface of the balcony above and is manually controlled. The basement studio-apartment on the south-west side is in a compromised position since it receives little sunlight. Given that windows are concentrated in the two opposite facades of the building, the windows can be operated to make a positive contribution to the ventilation of the building interiors and reduce the heat load through natural ventilation. [11, 20].

Description of the materials

The purpose of this section is to analyze the construction materials, finish materials and the surface materials of the building. These common to buildings constructed before 1980 and drive the relationship between the building's thermal performance and the climatic conditions in Heraklion. The supporting structure of the building is concrete made with Portland cement containing fly ash, while steel is used as reinforcement [10].

External walls are constructed of a double row of bricks separated by an air space and the internal walls are made of a single row of bricks. The roof of the building is a concrete slab roof with modestly sloping surfaces for the run-off of rainwater and is covered with terrazzo tiles. No insulation has been added to the roof. In the common use areas of the apartments (living room, kitchen and corridor) terrazzo is used for the internal floors. The bathroom uses ceramic tiles. Terrazzo was used for balcony floors. In the common use areas of the building, (the main entrance and the staircase) the floor was clad with marble. Marble was also used for the external paving surfaces of the building.

Initially, the external wall of the building was plastered and painted with white and beige paint. It should be mentioned that the majority of the materials are produced by small local manufacturers. In 2008, the central section of the facades were retrofitted and covered with ceramic tiles (0.10m x 0.10m) and the color of the facade was changed to white and bright blue.

3. ENERGY BEHAVIOR OF THE GREEK RESIDENTIAL BUILDING

The residential buildings are considered a significant energy consumption sector. The energy used for heating, cooling, hot water and appliances, are reviewed in this chapter, along with the design characteristics; the floor area and the climatic zone of the dwelling that drive the energy consumption [9].

The annual average energy consumption in Hellenic apartment buildings constructed since1980 in climatic Zone A, on a unit floor basis, is 24.6 kWh/m² for electrical energy consumption and 65.3 kWh/m² for thermal energy consumption (fuel oil or natural gas). The increased energy consumption for space heating is due to lack of insulation and poor boilers maintenance [10]. Based on energy conservation measurements, up to 60% of the total energy used in buildings constructed before 1980 results from space heating [8, 21].

Energy price is an important consideration on the source of energy consumed in households. The constant increase in oil prices in Greece and the taxes for oil space heating exacerbates the problem; income levels which have been decreasing in the last years.

Greece is characterized by hot climate conditions and long duration summer periods. Air conditioning units, typically mini-split-units are the main cooling devices installed in residential buildings. In most instances they have been added since the initial construction. The installations of mini-split-units provide the lowest initial cost for air-conditioning systems. Mini-split units configured with a compressor located outside adjacent to the external wall with the evaporator in the building's interior close to the openings; the refrigerant circulating between the two units. In Greece the total installed electrical capacity of split units is more than 3,500 MW, with an annual growth of 200MW per year [22]. The use of such systems during the cooling period (June to September) can independently control the indoor temperature based on the personal comfort of the residents. Their extensive use during the summer days and the limited capacities of the power plants in Greece, has contributed to serious disruptions of the Greek power [23].

Heating and cooling loads have an important role in thermal comfort and affect energy consumption. Based on ASHRAE 55 [24], thermal comfort is a complex interaction of different variables such as the climatic conditions, sensitivity of occupants and their metabolism, clothing and other parameters cannot necessarily be applied from the U.S standard.

The occupancy patents are also critical in developing an understanding of the space heating and cooling demand in a building. For this purpose it would be important to understand the average daily occupancy of the study building (shown previously in Chapter 2), (see Figures 10, 11, 12, and 13).

The favorable geographical position of Greece and its extended number of wide sunny days during the entire year results the extended use of these solar collectors. Since 1975, right after the first oil crisis, Greece represents a growing market in solar collectors. Their primary advantage is the reduced electricity bills, especially now where the prices of oil and electricity in Greece are in constantly increasing. Financial Government grants of DSWHS with tax reduction (law 814/78), advertizing and local private investments of Greek citizens led the Greek thermal solar collector market to a leading position in the European market, representing 25% of thermal solar collector market in the EU by 2002. Their annual energy production varies from 350 kW h/m^2 to 800 kW h/m^2, while their cost is related to the hot water consumption during the year[25, 26].

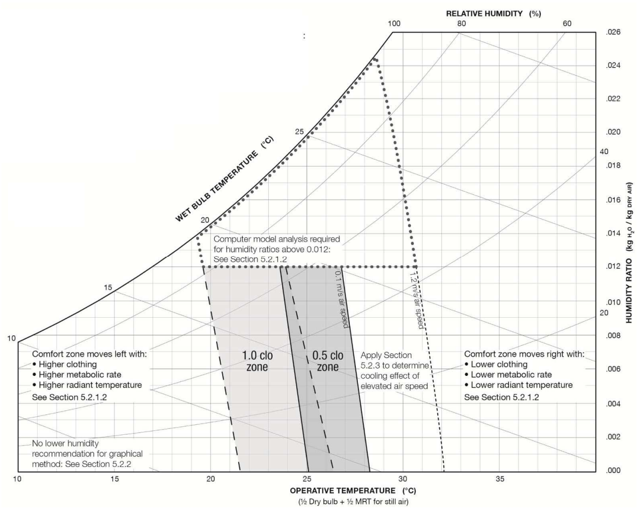


Figure 9: ASHRAE comfort zone [22]

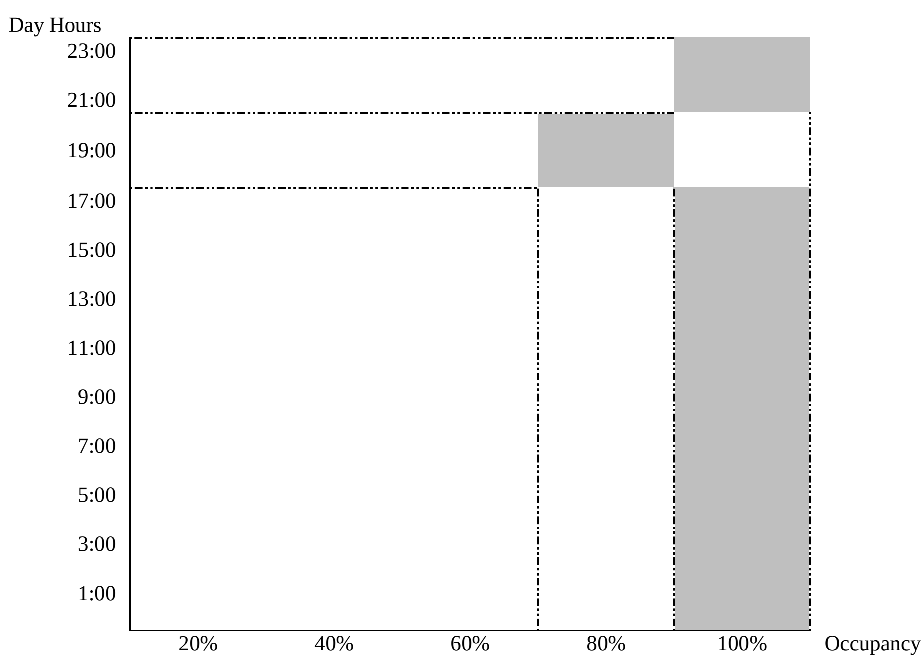


Figure 10: Typical occupancy schedule for ground floor

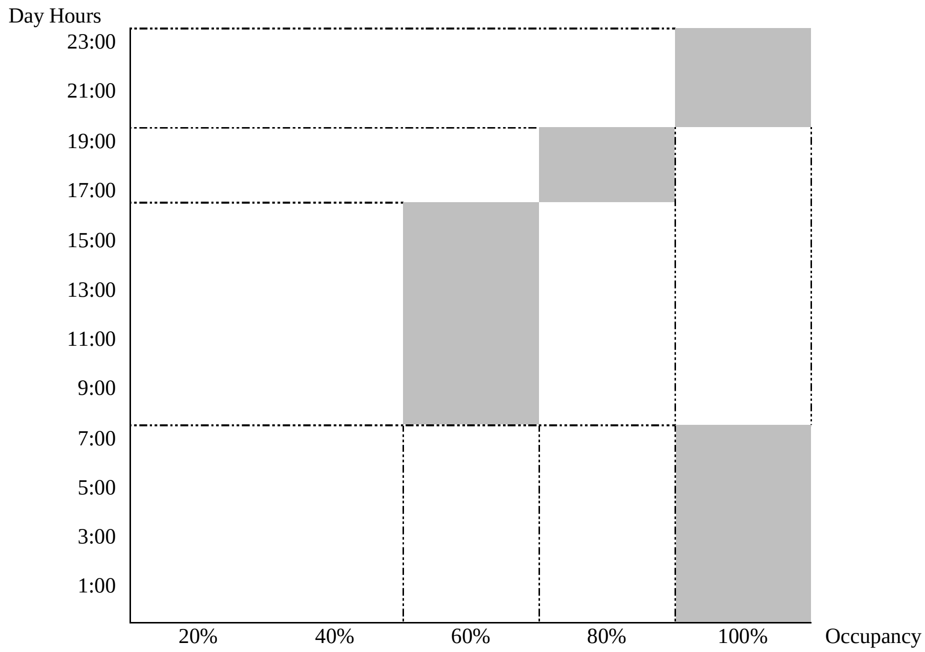


Figure 11: Typical occupancy schedule for 1st floor

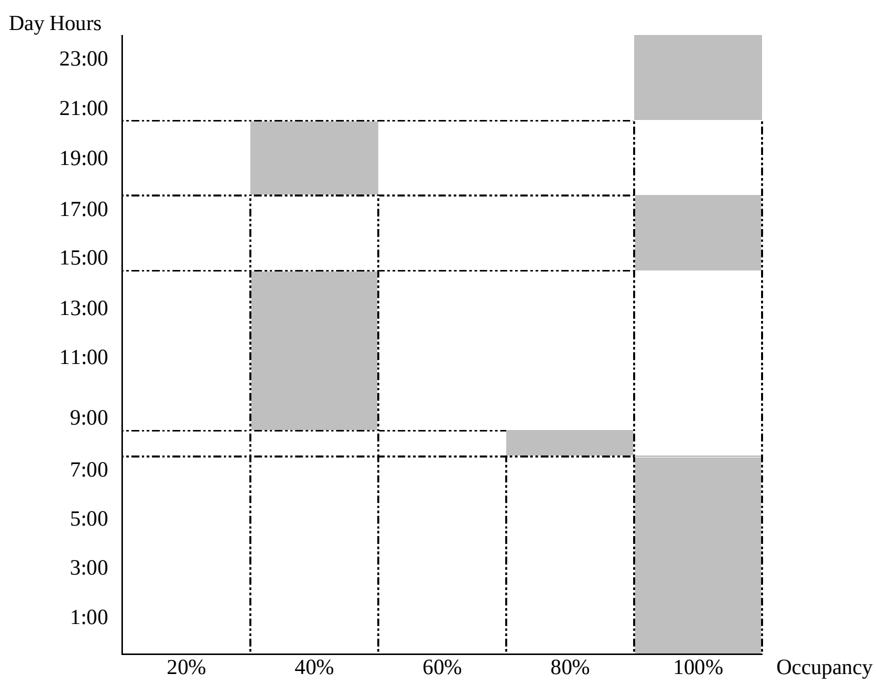


Figure 12: Typical occupancy schedule for 2nd floor

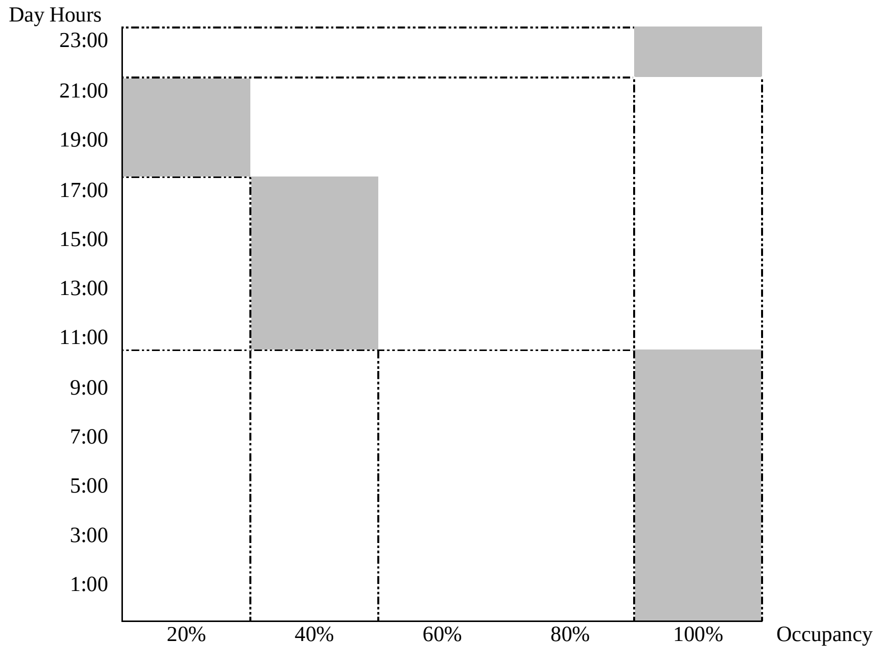


Figure 13: Typical occupancy schedule for 3rd floor

Systems

To understand the building's energy performance it was necessary to further define the proprieties of the buildings including the envelope thermal insulation, the characteristics of the heating and cooling equipment and of the domestic hot water system. The average number of occupied space per person is also an important consideration in the energy analysis of the household (see Figures 10-13).

Description of thermal insulation

In the examined building no supplemental thermal insulation protection was applied in the building shell. A large proportion of the Greek building stock was constructed before the introduction of the Thermal Insulation Regulation (TIR) in 1979 and as a result do not contain any external envelope insulation [13] [17]. High heat gains occur through glazing and external walls, while heat gain through the building's roof primarily affects the apartment in the last floor [19]. The poor envelope construction affects the thermal energy performance and results in increased energy consumption for heating the space.

Description of the heating system

The central heating system, located in the mechanical room in the basement floor is fueled by an oil-fired boiler with a nominal capacity of 115kW and distributes the heat to hydronic radiators, positioned in every apartment near the external window openings. According to the Hellenic Ministry of the Environment the "projected" heating cost for each apartment is related to its volume and its window opening's surface area [17] [13]. During the heating period (November to March), the apartment's indoor temperature is kept close to 21°C from 6:30am to 8:30am and 6:00pm to 9:00pm. The second and the third floor apartments will have smaller heating loads compared to the ground floor and the fourth floor apartments which are exposed to the ground and ambient temperature respectively. The ground floor studio-apartments and the fourth floor apartment are in a more unfavorable position since heating loss is higher. As a consequence, higher heating capacity is required to maintain the indoor temperature in the same levels, especially during the morning hours and during the night. The daily duration of heating is approximately five hours per day; two hours in the morning and three hours during the evening. Regarding the maintenance of the heating system, the boiler unit is maintained on an annual basis. The increased energy consumption for space heating can be explained by the unsatisfactory comfort conditions due to the poor performance of the building shell. In this case-study building this results in an overall average annual consumption for space heating of 1500 liters of oil (for all of the conditioned spaces).

Description of cooling system.

The majority of the apartments are equipped with autonomous cooling systems, which are separate from the centralized heating boiler. Unitary air to air heat pumps, splits-units with the compressor placed externally and evaporators in the interior near the openings, are located in three apartments. This units have an average capacity equal to 9000 BTU/h. This size of units is typical for small apartments in the climatic zone conditions of Heraklion.

Considering the cooling loads, the third floor apartment will experience the higher cooling demand during the summer season because of the absence of thermal insulation protection in the flat roof and the exterior walls.

During the cooling season the residents keep the windows open and the mini-splits are off. When the area is getting too warm, occupants spend significant time in the outdoor spaces. This is in common in Greek residential buildings. The air-conditioning systems are usually operating three hours in the after-noon when the outdoor temperature is over 32°C.

Description of domestic hot water

The production of domestic hot water comes from three solar collectors in the roof of the building, supplemented by electric hot water boilers. The apartments on the ground floor, second and third floor, use solar collectors, contrary to the first floor apartment where the annual hot water production is covered using only a 4kW electric hot water boiler. The average required temperature gain for hot water production is around 19 ºC while the monthly consumption depends on the number of occupants in the building and is estimated as 2.5 liters/m²/day. The existing thermal solar collectors located in the flat roof are facing towards south-east. They are inclined at 45° to the sky and are shaded by the surrounding buildings or the building itself. Each solar collector has an area of 3.28 m² with a 200 liters boiler and a 1 MT storage tank each. In addition three storage water tanks, 2 MT each, are connected to the water tanks in the roof, while a 4kW electrical resistance boiler system is being used as backup. Since the building is located in the Thermal Zone A, in the south part of Greece, the percentage of energy savings due to the solar collectors is 74% [19] as compared to an all-electric system. The solar collectors were installed in 2008. The cost (initial investment and installation cost) was estimated to be 1,000 Euros.

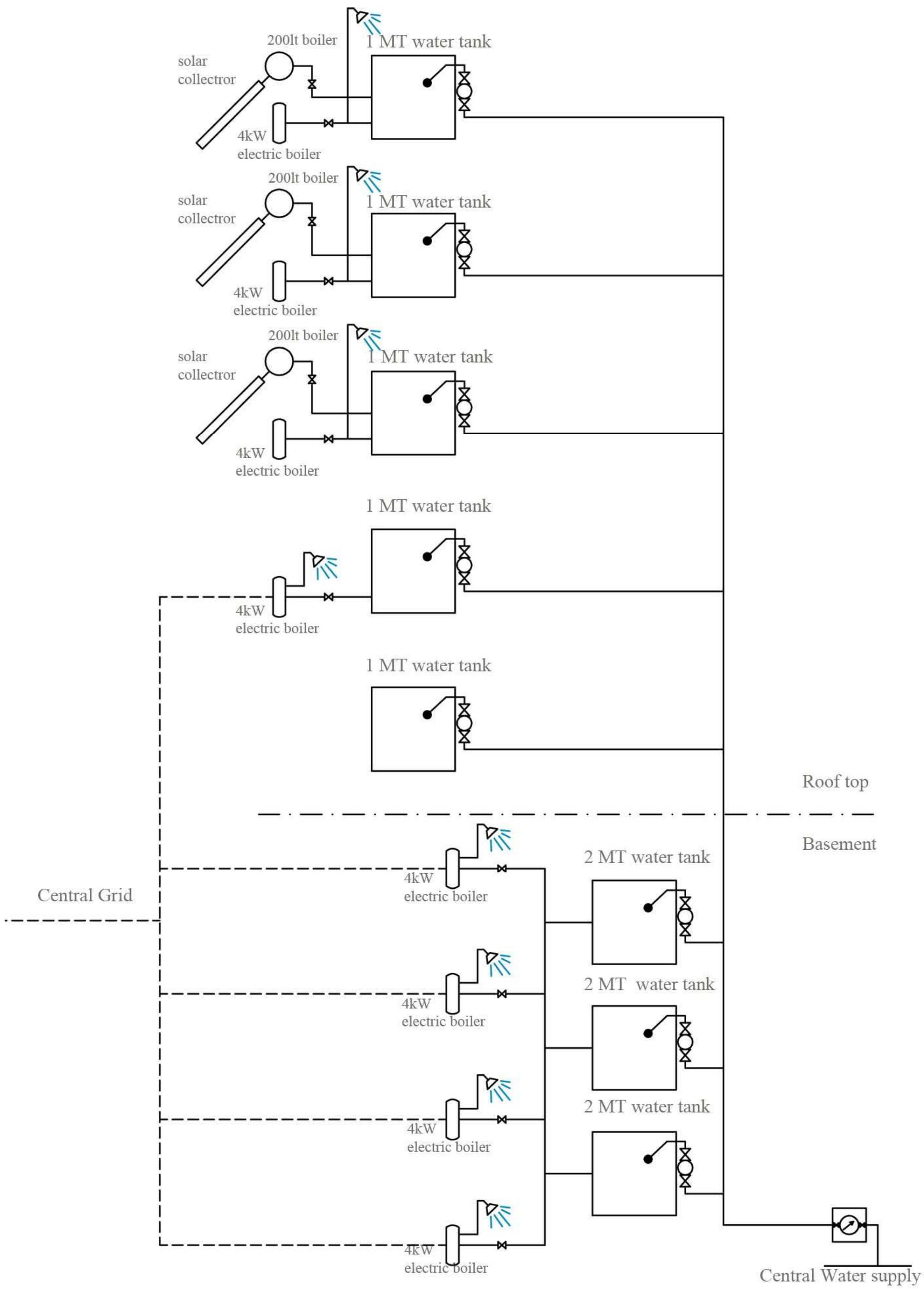


Figure 14: DHW system

Description of electricity energy consumption

Based on data from the Public Power Corporation (Δ.Ε.Η) [15] the average annual electric energy consumption per capita in 2007 was 4970 kWh.

Table 4: Average value of electric consumption per capita [15]

Year	1950	1960	1970	1980	1990	2000
Kwh	88	265	976	2106	2923	4113

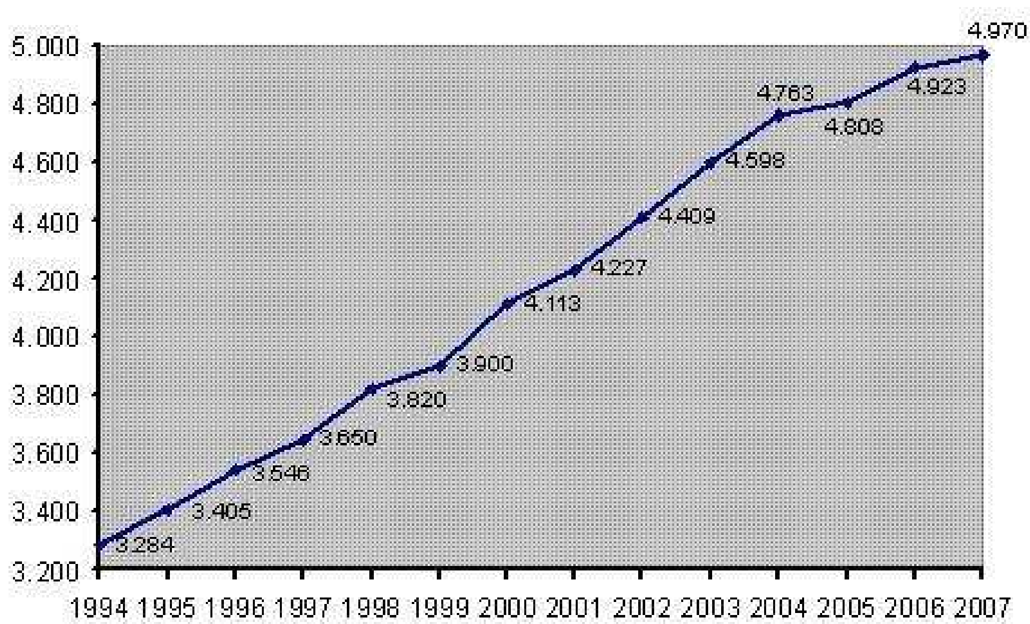


Figure 15: Yearly per capita Electricity consumption (kWh)[15]

As shown in figure 15 there is a linear increase of the electricity energy consumption throughout the years. The annual increase of electricity demand during the last decades can be related to the increasing number of installed air-conditioning cooling devices. During the last decades, significant ambient temperature rise combined with global warming effect resulted in a relative increase of air-conditioning split units usage [12, 27]. It is worth mentioning that electricity in Greece is produced by coal based generators. The need for thermal comfort and the extensive usage of air conditioning result in frequent peaks of the electricity demand that occur during the summer period.

4. ENERGY CONSUMPTION

The review of the annual energy consumption (in this case study, electricity and heating oil) is key indicator of the primary energy use in the building. It is valuable to compare energy bills, which show gross energy usage, but not a breakout by system, with calculations that predict the amount of energy that each system should consume. For the purpose of estimating and comparing the annual consumption values given from the detailed annual utility bills, an energy analysis tool is used, namely the “Energy Performance Calculator”, developed by the Prof. Godfried Augenbroe at the Georgia Institute of Technology.

Data regarding the general construction characteristics of the building, the envelope characteristics, the materials of construction, as well the operating systems and the energy related to their operation, were used to develop a base model of the building. Moreover, it was necessary adjust the climatic parameters of Heraklion to the weather values required for the calculation tool. For that purpose a weather file was created corresponding to the weather conditions present typical in Heraklion. Information provided by the Hellenic National Meteorological Service, EMY [28], indicated that wind represents an important factor on the weather formation. The city of Larnaca in Cyprus represents a latitude close to that in Heraklion. The weather file therefore used climatic data from TMY for Larnaca, along with the wind direction and speed presented in Heraklion. The intention of this aspect of the study is to analyze the energy use of the building by energy source, using the EPC calculation tool, and compare this with recorded energy use.

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Consumption of heating oil electricity and water

Greece is still suffering from the recent economic downturn in Europe. Heating oil and electricity prices are trending higher while average households' incomes are stable or even lower than those in the past two years. The actual energy consumption and costs for energy, for the case-study building are provided in Tables 5 and 6, below, for an 18 month period from. These bills span the dates of November 2009 to October 2010. For the evaluation of the utility bills, the energy consumption and cost estimate it is considered a total value of the four dwellings in the entire building. Bills for electricity in Heraklion are provided on a quarterly basis (Table 5). Bills for fuel oil do not occur at consistent intervals, as the fuel oil tanks are filled when the tanks become low (Table 6). Bills for water consumption are also provided (Table 7).

Table 5: Four-month period electricity consumption

Period	Electricity Consumption (kWh)	Cost (€)
Nov/Dec/Jan/Feb	3651	373
Mar/Apr/May/Jun	3416	358
Jul/Aug/Sept/Oct	3248	340
Total	10315	1071

Table 6: Three and two-month period heating oil consumption

Period	Oil Consumption (L)	Cost (€)
Jan/Feb/Mar	1000	642
Nov/Dec	500	346
Total	1500	988

Table 7: Three-month water consumption

Period	Water Consumption (m^3)	Water Consumption (Liters)	Cost (€)
Jan/Feb/Mar	140	140,000	211
Apr/may/Jun	132	132,000	200
Jul/Aug/Sept	134	134,000	203
Oct/Nov/Dec	120	120,000	182
Total	526	526,000	796

Since the four-month period does not represent analytical monthly electricity consumption, it was necessary to develop a strategy to break the electrical energy use down by use categories. For that purpose a constant monthly amount of electricity is deducted for use by the appliances, (see Table 8).The available data determine the operational schedule of the appliances given in Table 8, results from residence's observations.

Table 8: Electricity consumption of appliances

Appliances	Function-Time (h/day)	Number of Dwellings	Consumption (W)	Monthly Consumption /Dwelling (kWh)	Total Monthly Consumption (kWh)
Refrigerator	24	4	55	40	158
Television	3	4	150	14	54
Laptop	2	4	50	3	12
Electric oven	0.5	4	2300	35	138
Cooking range	1	4	1000	30	120
Clothes washer	0.25	4	425	3	13
Electric water heater	0.16	4	9000	43	173
	1	4	1000	30	120
Total				197	668

To have a more detail overview of the overall electricity consumption, further assumptions on the use of lighting is necessary, (see Table 9). An important factor of the lighting energy consumption is the type of light bulbs used. In this study the use of fluorescent light bulbs was confirmed with the building occupants. The lighting usage during the day differs by the seasons as well. In Table 9, is shown the percentage of monthly lighting use and how that affects the total electricity consumption. Based on the seasonal daylight duration, the occupant's schedule in the building and the constant electricity consumption of the appliances, lighting use per different month is determined.

Table 9: Monthly electricity consumption according to daylight use

Period	Electricity Cons. per period (kWh)	Electricity Cons. appliances (kWh)	Monthly Percentage Lighting (%)	Monthly Lighting Cons. (kWh)	Monthly Electricity Cons. (kWh)
March	3416	744.20	29	215	883
April			27	198	866
May			2	198	866
June			18	132	800
July	3248	576.20	21	118	786
August			23	133	801
September			26	148	816
October			31	177	845
November	3651	979.20	24	232	900
December			27	266	933
January			25	249	917
February			24	232	900
				9546	10315

The fuel oil storage tanks are re-filled twice a year. The filling takes place in November; right before the winter season and the second one occurs in January, during the middle of the heating season. Since it is considered a two-month period and a three-month period of heating oil consumption, based on residence's observations on dally heating schedule, it is necessary to identify the monthly variation of oil consumption.

Table 10: Monthly heating oil consumption

Period	Heating oil cons. per period (L)	Daily durat. of heating (h/day)	Monthly percentage (%)	Monthly heating oil cons. (L)	Monthly heating oil cons.(kWh)
January	1000	5	36	360	4248
February		5	36	360	4248
March		4	28	280	3304
April			-	-	-
May			-	-	-
June			-	-	-
July			-	-	-
August			-	-	-
September			-	-	-
October			-	-	-
November	500	4	47	235	2773
December		4.5	53	265	3127
Total					17700
fuel oil=11,8kWh/liter					

Considering and the monthly energy consumption and the previous analysis, it is clear that the heating oil consumption is higher than electricity consumption, (see Tables 9 and 10, Figure 16

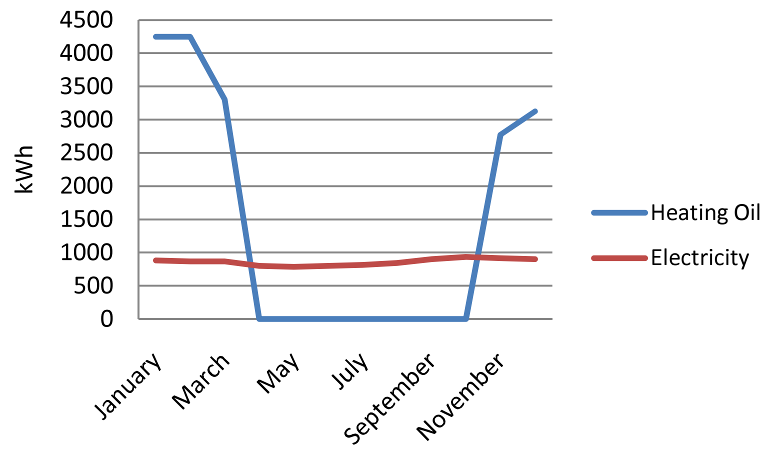


Figure 16: Electricity and heating oil annual consumption (kWh)

It can be concluded from the energy consumption relationships depicted in Figure 16 that the relationship between the electricity and the heating oil consumption during the different seasons is related to the type of the construction, the type of the equipment used in the building, the climatic conditions of Heraklion (the primary actor here), (see Tables 11, 12, 13 and 14) and the size and the age of the building. As was discussed previously, the use of air conditioning is rare and it does not significantly affect the total electricity consumption. In many parts of the United States, we would expect to see a peak in electricity use in the summer months (June through August). The energy consumption in Heraklion shows no such peak.

During the summer season there is an unexpected reduction of energy consumption that proves the use natural ventilation instead of air conditioning. Due to the presence of the mini-split air-conditioning units, it was anticipated that the use of these units would lead to increased electrical consumption during the summer. For the data provided in this study, that is clearly not the case, (see figure 18)

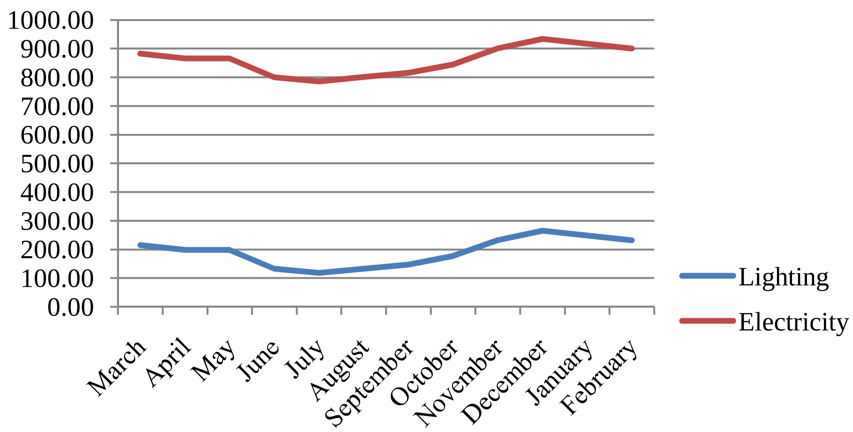


Figure 17: Electricity and lighting annual consumption (kWh)

All the above calculations, along with the residence's observations on air-conditioning use, confirm this consideration. In winter months, it is evident that the high energy consumption can be explained by examining the poor envelope construction. The excessive consumption of electricity use during the winter months can be associated not only with the lighting increase but it also can be linked to the increasing percentage of heating. Though the primary consumption of energy in the boilers is fuel oil, there is significant energy associated with the pumps and other electrical systems that are tied to the boilers.   The correlation between energy use and outside temperature in the winter is clear.

5. ANALYSIS OF WEATHER CONDITIONS

Relevant climatic data is required for any type of energy analysis in an urban environment. Different climatic variations are related to the increase of the cooling or heating demand in an apartment unit. To understand the building's energy performance it is important to describe the local climate parameters of the studying area [12, 29], as well as the influence of the thermal human comfort inside the building [27]. Climate conditions and temperature variations are determined by the geometry of the buildings, the solar radiation distributed on the surface of the buildings (roof, facade), the nature of the surrounding area, the material's proprieties and the fuels released in the environment [11].

However, climate conditions have psychological and behavioral implications to the living style. As it was mentioned before, during warm days people in Greece spend significant time in the outdoor spaces. Opening of windows is a common practice in residential buildings during the summer. This fact demonstrates their adjustment in the local climate conditions, and justifies the relationship between the indoor and outdoor comfort according to the external temperature. It is evident that thermal comfort differs between people [24]. In a considerable number of residential buildings in Greece there are different ways o apply individual thermal control and comfort, either using operable windows or air conditioning systems.

The city of Heraklion, capital city of the island Crete in the north part of Greece, is located by the sea and is characterized by a warm Mediterranean climate with mild winters and warm dry summers (Longitude 25°44', Latitude 35°00', Altitude 13m). The average temperature during the summer is close to 26°C. Moderate mountains dominate on the western and southern side of the city. The eastern site consists of a low rise landscape while in the north part broaches the Cretan sea. The geography of a region constitutes an important factor on the study of the buildings performance. The hot and dry summers are characterized by cool waves of North West wind that favors the heat balance of thermal conditions in the city; while the short period of heating during the winter is reflected in the weather conditions. Observation of the monthly variations, the maximum and minimum temperature, as well as humidity, rain and prevalent winds are listed in the Tables 11, 12, 13 and 14. The selected climate data were posted by the Hellenic National Meteorological Service ,EMY [28], as well as the website “Weather Underground” [30].

An important factor that influences the selection of the building construction materials [5] is the seismicity of the region especially in Crete which is located in the South Aegean, one of the most seismic active zones in Europe, between the African and European lithospheric plates. The usage of materials with high resistance in earthquakes, such as concrete, still reinforcement and bricks walls, influences the thermal behavior of the building stock.

Climate data have an important role in energy simulation software programs and the assumptions used on the energy behavior of buildings. In the Mediterranean where climate is characterized by warm to hot and dry summers it is difficult to achieve thermal comfort inside the buildings.

As it was mentioned before, the air conditioning usage during high temperatures has important consequences on the contribution of pollutant elements in the environment, besides the impact on the electricity demand. Heat island effect, a phenomenon that characterizes Greece, is associated with the consequences of the demand of urban environment and the changes of the local climate conditions. According to EMY, Hellenic National Meteorological Service, the wind flow direction in Heraklion during the spring, summer and autumn seasons (March to October) is north-west and during the winter is north [28, 31]. The two opposite openings in the north-west and north-east site favored from the wind direction provide a higher rate of ventilation. Santamouris [11, 20] in his extensive study in both wind potentials and natural ventilation in urban areas takes into account the impact of significant parameters, such as the wind velocity, the latitude, the local effects, the air temperature, the position of the building, the openings area as well as the effects of other criteria such as the urban canyon, the surrounding and the operation of mechanical systems in the building. The effectiveness of cross ventilation is primarily based on the difference between the indoor and outdoor temperature, as well as the wind velocity.

Regarding the wind direction, the air direction is perpendicular to the facades of the building, creating a circulation of the air from one side to the other. It is worth noticing that during cooling months the temperatures are recorded to be higher than 23°C [28, 31] and the north-west wind flow appears to be favorable on the ventilation of the building interiors, replacing indoor air with outdoor air providing also an air quality and thermal comfort in the cooling period [21, 22]. The indoor comfort temperature during the summer months is difficult to be controlled, and is among the greatest challenges that architects and mechanical engineers have to face.

The study of the weather data demonstrates a relatively high amount of solar isolation and a relatively constant humidity throughout the year. The wind has drastic effects on the amount of infiltration in a building shell. The effect of temperature depends also on the wind direction. Considering these two factors we can determine the prevailing winds favorable to north-west, well-disposed to the position of the building. The information presented in Tables 11-14 allows the understanding of the weather conditions but it is also a tool to determine the best retrofitting strategies that will be followed.

Table 11: Humidity in Heraklion

1^o Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Humidity	68.0	66.1	66.0	61.7	60.8	56.3
2^o Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Average Humidity	56.6	58.3	61.2	65.5	67.7	67.7

Table 12: Temperature in Heraklion

1^o Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature	9.0	8.9	9.7	11.8	15.0	19.1
Monthly Average Temperature	12.1	12.2	13.5	16.5	20.3	24.4
Monthly Max Temperature	15.3	15.5	16.7	20.0	23.5	27.3
2^o Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Min Temperature	21.6	21.8	19.3	16.5	13.4	10.8
Monthly Average Temperature	26.1	26.0	23.5	20.0	16.6	13.7
Monthly Max Temperature	28.7	28.5	26.4	23.4	20.0	17.0

Table 13: Wind in Heraklion

1^o Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	S	S	NW	NW	NW	NW
Monthly Average Wind Speed	9.3	9.9	9.1	7.9	6.3	6.8
2^o Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Average Wind Direction	NW	NW	NW	NW	S	S
Monthly Average Wind Speed	8.9	8.9	7.7	7.4	8.1	9.4

Table 14: Rain in Heraklion

1^o Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Rainfall	90.1	67.6	58.2	28.5	14.2	3.5
Total days of Rain	16.0	13.6	12.0	7.7	4.4	1.3
2^o Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Average Rainfall	1.0	0.6	17.7	64.9	59.0	77.9
Total days	0.3	0.4	2.4	7.8	10.6	15.1

6. GREEK EPBD DIRECTIVE - KENAK

Greece and all the other European Union member countries are in accordance with the European Directive 2002/91/EC, EPBD, on the energy performance of buildings.

Based on the Kyoto Protocol agreement the European Union has to achieve by 2012 an overall 8% reduction of Greenhouse gas emission in comparison with the 1990's emissions [13]. In 2000 the "European climate change program" ECCP was launched with the aim to initiate a common strategy to implement the commitments of Kyoto Protocol. According to the Kyoto Protocol carbon dioxide (CO_2) emission targets, Greece emits 9.10% of the overall percentage of Kyoto target.[32]

A priority has been given to the building' energy efficiency improvement. For that purpose a new directive was introduced to evaluate the energy consumption in buildings. Finally in 2002, all European state members under the Concerned Action, CA "Energy Performance Building Directive" EPBD, 2002/91/EC, would promote the energy efficiency in new buildings as well as existing buildings under specific conditions, using a different approach each one. All European member countries should implement a methodology which corresponds best to their regional level in order to achieve the minimum requirements of the directive.

The objective of the new Directive is to approach different factors that determine the energy efficiency in buildings in terms of external insulation, heating and air-conditioning systems and renewable energy sources in order to improve their energy performance. This requires a study of transmission losses, internal heat gain, natural and artificial lighting, heating and cooling requirements and water consumption. Moreover the climate and local conditions and cost effectiveness constitute an important approach to this process[1]. As it was mentioned before, high temperatures during summer lead to important problems and result in several electric black outs.

According to the official Journal of the European Communities, priority should be given to the countries in southern Europe to approach the building's energy performance during the summer season, as well as the passive cooling techniques to improve indoor conditions.

The results are presented in a mandatory energy performance certification which indicates the energy performance situation along with energy saving measures for a) new buildings under construction b) existing buildings and c) buildings under major renovation. The regulation has been standardized by the European standardization organism with the ISO 13790.

KENAK

In Greece, the regulation of energy efficient buildings KENAK refers to the standard ISO 13790 as well as other international standards that define all the parameters related to the Greek requirements. Since the implementation of EPBD, there were not any specific regulations defined in Greece regarding the energy performance and the evaluation of buildings. The only regulations related with the thermal performance of building were the national Thermal Insulation Regulation (TIR) introduced in 1981 and the Technical codes related with the installation of heating and cooling systems[33]. The thermal insulation regulations required to achieve low U values. The smaller the U value is, less thermal loss exists and the better the insulation of the building is. The U value had to be lower than the value that the regulations indicated.

Table 15: Minimum U values according the new and previous regulations[34]

Minimum Requirements according to the new Regulation		U-value [W/m².K]			
		Climatic Zone			
		A	B	Γ	Δ
Roofs	U_{V_D}	0.50	0.45	0.40	0.35
External Walls	$U_{V\text{-}W}$	0.60	0.50	0.45	0.40
External Floors	U_{V_DL}	0.50	0.45	0.40	0.35
Floor over ground	U_{V_G}	1.20	0.90	0.75	0.70
External walls in contact with the ground	U_{V_WE}	1.50	1.00	0.80	0.70
Openings	U_{V_F}	3.20	3.00	2.80	2.60
Glass Facades	U_{V_GF}	2.20	2.00	1.80	1.80
Minimum Requirements according to the PREVIOUS Regulation		**U-value [W/m².K]**			
		Climatic Zone			
		A	B	Γ	
Roofs	U_{V_D}	0.50	0.50	0.50	
External Walls	$U_{V\text{-}W}$	0.70	0.70	0.70	
Floor over ground	U_{V_G}	3.00	1.90	0.70	
External walls in contact with the ground	U_{V_WE}	3.00	1.90	0.70	

As Greece failed to fulfill its obligations to abort the measures agreed by the EU counties related to the Directive 2002/91/EC in 16 December 2002 on EPBD, the European court forced Greece to pay the cost [35]. The fast implementation of KENAK was a result of the European Court punishment in 2008.

Finally in April of 2010 in compliance with the Directive 2002/91/EC the Hellenic Ministry of Environment, Energy and Climate Change (YPEKA) [36], which is responsible for the national EPBD and the Technical Chamber of Greece, launched the Regulation on Energy Assessment of Buildings KENAK in accordance with the national law N.3661/2008 adopted in 2008.

According to KENAK the energy evaluation in buildings determines the energy efficiency through a series of detailed analysis. The rate of the building in the energy efficient indicator is defined by an energy performance certification that specifies different energy level classes, related to the different climatic zones and the type of use of the building. This indicator is expressed in kWh/m² per year. The KENAK also defines the inspection of boilers, air-conditioning systems and the buildings in general in order to promote the overall improvement of energy performance of buildings in Greece. Recommendation of alternative options for energy saving and information related to the improvements on the energy efficiency of the building would be suggested by the inspectors in order to inform the owners for future investments to improve the energy performance of their building.

KENAK –Directive Requirements

Calculation Methodology

To begin with, it is important to distinguish two different terms relevant to the procedure of energy efficiency calculation. According to the ministerial decision [34], a reference building is a building having the same shape, orientation, usage and operation characteristics with the buildings under consideration.

As it was mentioned before, nine different categories, from A+ to H, classify the energy efficiency of buildings. Three categories above the category B (A, A+, B+) indicate the most competitive energy efficient buildings. The classification of the building in the rating scale is calculated based on the primary energy consumption of the examined building. Figure 19 represents an example of the energy scale indicator. Moreover, each certificate provides the total Co2 emissions of the building, the actual energy consumption based on the energy bills, and a qualification on the thermal visual and acoustic comfort of the building. Buildings under inspection would be new buildings, existing buildings under major renovation and buildings or apartments in sale or leasing.

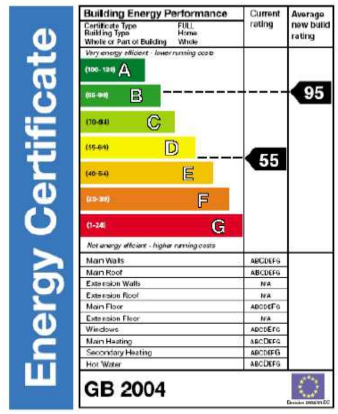


Figure 18: Energy Rating Certificate KENAK [1]

The minimum classification required for new construction and renovated buildings is the running scale B. In case of selling or leasing an apartment the value of the property is affected by its classification in the energy efficiency range. That action means that owners have to renovate their properties in order to increase the value of it.

Four different guidelines, referred as T.O.T.E.E 20701-1, 2, 3, 4/2010, published by the Technical Chamber of Greece (TEE), describe the mandatory parameters such as the thermal proprieties of building materials (TOTEE 20701-1/2010), HVAC energy inspections (TOTEE 20701-2/2010), national weather data of different Greek locations (TOTEE 20701-3/2010) and the analytical methodology that should be followed for the calculation of the reference building (TOTEE 20701-4/2010).

As it was mentioned before in order to study the energy rate in buildings the Greek territory has been divided in four climate zones based on the heating degree days. Since now the climate zones had been defined according to the existing national Thermal Insulation Regulation TIR. The climate zones are crucial in how weather conditions influence the energy behavior of the building. In this case study, the location of Heraklion where the building is situated in, belongs in climatic zone A.

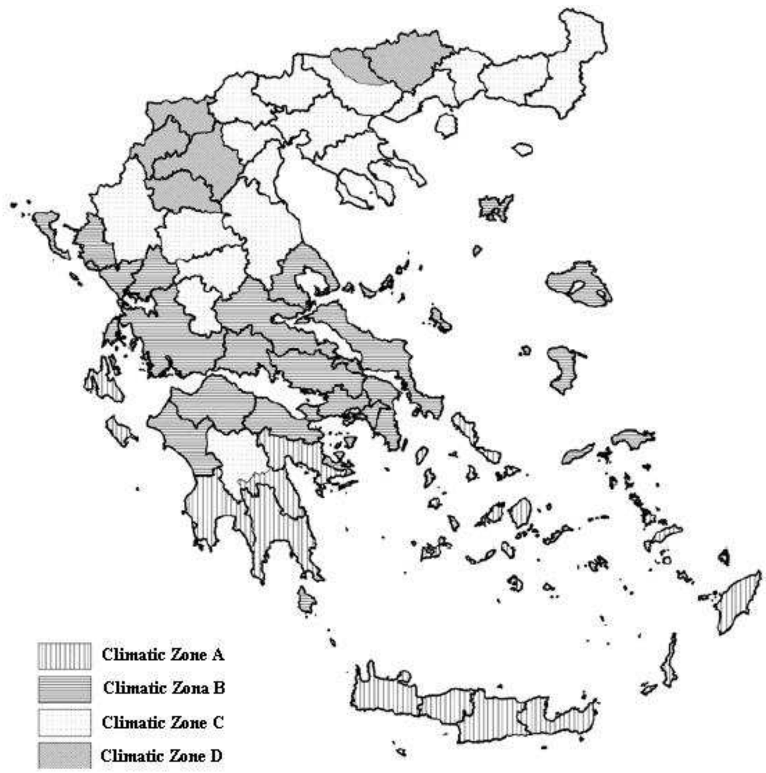


Figure 19: Climatic zones according to the new energy performance regulation (KENAK) [37]

The purpose of the division in different zones is to facilitate the design process of the minimum and maximum capacity of heating and cooling systems individually, in order to cover the extreme seasonal temperatures presented in each different zone [37]. Based on the different climate Zones the dimension capacity for the cooling and heating systems has been defined, in order to cover the extreme seasonal temperatures. In the guideline “Climatic Data for Hellenic Zones” the values listed regarding the zone A, are very similar to these presented in the previous chapter “Analysis of weather conditions”.

TEE KENAK Software

For the implementation of EPBD it was necessary to use a software tool in order to calculate the energy performance, rate the Building and finally lead to the Certificate of Energy Efficiency. The Technical Chamber of Greece with the partnership of National Observatory of Athens NOA [28], developed the software TEE-KENAK. The software is a upgraded form of the calculation software product EPA-NR “Energy Performance Assessment of existing Non-Residential buildings” developed to accomplish the need of EPBD and is adapted to the local requirements of Greece [38]. The software incorporates the Technical guidelines, TOTEE 20701-1, 2, 3, 4/2010 and the regulations of KENAK as electronic libraries installed in the software to collect all the information required for the design of the existing building[39]. The calculation methods have been certified by the European standard ELOT (Hellenic Organism of Standardization) EN ISO 3790[40] ,

Energy Inspectors and Inspections

Besides the regulations of the new Directive, the KENAK requires the inspection of heating and air-conditioning systems. Specialized persons, referred to as “Inspectors”, inspect and ensure the correct application of KENAK in different building categories.

Energy inspectors would issue the energy efficient certificates. The licensed Inspectors are categorized as a) Energy Building Inspector, b) Energy Inspector for heating boiler systems and c) Energy Inspectors for Air Conditioning systems. The Energy Inspectors must be Architects or Engineers, registered members of Technical Chamber of Greece. Moreover, Graduate Engineering Technicians with four years of professional experience can gain the recognition of inspector. The authorized Inspectors should be trained before they get the permission of audits as well as they have to successfully pass the required qualified exams. Furthermore, they should be under the supervision and control of a national department of licensed experts.

Based on their academic background, the inspectors would be certified to carry out different types of audits, divided into two different license categories. The first category (A) authorizes inspection for construction of a building with a total floor area less than 1000m² instead of the category (B) that concerns inspection of buildings that exceed 1000m². [41-43]

Controls

In case of new constructions, the certificate lasts for ten years. The buildings under major renovation are required to be certified again to evaluate their energy efficiency. A second review has to take place two years after the certification of the building. Once the control is completed, energy consultants check the validation of the certificates. In case false information is observed, a penalty is issued to the inspector and the owner too. The penalization for the inspector, depending on the severity of their offence, could be their exclusion as energy reviewers for a couple of years or their total exclusion as inspectors. Regarding the owners, in case the construction does not meet the requirement of its certification, the building would be considered as an illegal construction and the building has to be reviewed and upgraded in order to improve its performance according to the minimum requirements of the KENAK[42, 43].

Renewable

With the recent adoption of the Law L3851/2010 Greece is ambitious to increase by 2020 the national energy consumption from Renewable Energy Sources (RES) by 20%, 2% above the mandatory level of 18% set by Directive 2009/28/EC. This objective will be achieved through collaborations and energy efficiency measures named as “green development” that will increase the penetration of RES technologies in electricity production. Based on the law L3851/2010 specific regulations have been established for the use of RES in KENAK. Regarding the new legislation, new initiatives encourage the use of RES in energy consumption, electricity production and contribution in heating and cooling. Additionally, special programs and financial incentives for photovoltaic installation up to 10kW in the household sector and small businesses will encourage the development of RES use [44].

The new buildings and the one under major renovation must stipulate a minimum required level of energy from renewable sources. According to the new regulations 60% of Domestic Hot Water production should be covered by solar thermal collectors or alternative renewable energy production systems.

Financial Initiatives and Incentives

The Government of Greece has developed a project named “Exikonomo” (Energy saved at home) with the aim to improve the energy performance of existing buildings and improve the standard of living. The total cost of the project is approximately 400 million Euros. Based on the funds contributed on it, each region will have a different economical enrolment on it. Owners will be eligible for funding based on the personal incomes. The incentives include free or low-interest loans and grants up to 30% of the eligible budget. The programs provide incentives for thermo- insulated frames with double glazing as well as external shading devices. Installation of insulation material can be applied on the external components of the building envelope including the roof.

Regarding the heating and cooling systems, heating oil or gas boilers can be replaced with a new one or with a renewable energy source system as geothermal heat pump and solar thermal pump including automatic control thermostats. In accordance with the new directive, solar collectors should cover a minimum percentage of the annually thermal loads in each different climate zone and the available area in use. In addition to that the project "Exiconomo" includes the installation of solar collectors and the installation of solar systems for hot water (storage water tank, mounting, piping, etc). Building insulation and external openings replacement are beneficial and effective energy saving actions [45].

7. PROPOSED RETROFIT STRATEGY

The purpose of this work is to develop a direct link between energy improvement and architecture in typical residential buildings in Greece. As this type of buildings represent a restrictive lack of architecture expressions, the proposed design would focus on the idea to reuse elements that characterize Greek architecture through a modern dialog while on the same time satisfying the attitude of the residents living in the outside space during the summer months.

The improvement of the energy behavior in the existing building is an important aspect of its energy consumption. Minimizing the requirement on the energy performance of the existing building can significantly reduce environmental impact and the energy consumption of the building.

To begin with, it was necessary to understand how building orientation and the local climate conditions contribute to its energy performance. The intent of the solar analysis in ECOtect was to acquire a better understanding of the sun path effect in the building block geometry, in the shape and position of the openings of the buildings and finally lead to design decisions. The sun path and the orientation of the building determine the changes in thermal strategy throughout the year.

Upon simulating the building in ECOtect, based on the monthly diurnal averages of the weather data and the thermal comfort on the incident solar radiation, it was noticed, that during the warmer months of summer high demands will be placed on the thermal comfort of the building due to the high temperature values. Based on the direct solar radiation, in order to decrease the amount of thermal load, it is important to study the solar exposure and the incident solar radiation of the main facades on the buildings. The 21st of each month was selected to examine peak conditions of daylight and shading throughout the year.

Through January to March and October to December, in the morning, the sun rises from the east, so the north-west facade of the building is totally under the shadow of the building itself and the surrounding buildings. During the spring and summer seasons (April to September) after 13:00, solar radiation gradually appears after north-west facade, with a low amount of light.

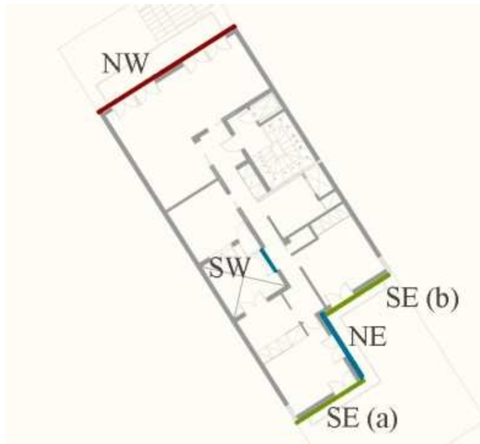


Figure 20: Façades orientation

Table 16: Average annual Solar Radiation

Façade orientation	Incident (W/m2)	Incident W	Absorbed (W/m2)	Absorbed W
South East (a)	9958	498929	4930	246970
South East (b)	4008	200804	1983	99398
North East (a)	4788	225731	2369	111735
South-West	1003	38236	496	18926
North West	220	21970	108	10876

The different amount of solar radiation in each facade of the building for each month allows to understand the different passive and active strategies for the better performance of the building.

Comparing the results of Table 16, the room located on the south-east (a) side of the building receives the most solar radiation during the year , especially in the morning hours because of the direct sunlight. The north-east part of that room (north-east (a)) receives 4788 (W/m^2) because of the shape of the building and the distance between the two parts in the south-east facade. The room located in the side of it is almost under the shadow of itself the whole year and the solar radiation is very low.

The results given from ECOtect analysis demonstrate that south-east façade receives the biggest amount of solar radiation during the morning hours while the north-west part receives afternoon lighting. As it is noticed by the documented photos the main façade is not uniform since different shade techniques have been used by the residents primarily for privacy reasons. Due to these references and the ECOtect analysis it was considered that external shading devices should be used. Metal sliding venetian blinds should be placed in the front of the balconies while the facades should be painted in white color. These interventions would not significantly affect the energy performance of the building but it could improve the personal comfort in the balconies, and would also be used to control the personal privacy of each apartment individually considering the aesthetic parameters of the façade. Buildings painted in white color and the use of venetian blinds characterizes the tradition Greek architectures. While venetian blinds are optimum shading devises that permit the wind penetration in the interior space, they also work as elements for privacy. The most common material for venetian blinds is wood. Since wood needs maintenance it was considered as an alternative to use metal. The metal frames can be rolled in a horizontal corridor where residents can adapt different percentage of shading/privacy.

It can be noticed from the drawings (see Figure 3), that kitchen is isolated from the dining area and the living room. The standards of living and the requirements of the modern world have changed our way of living inside the house. In modern western society kitchen represent an important space inside the house. Usually it is part of the living room and is associated with time of pleasure and gathering of the family. Back in time the cooking was a duty for woman and she was isolated from the activities of the other members. Considering this factor, in the proposed design project the division wall between kitchen and dining room should be eliminated allowing a collective circulation between these two spaces.

Figure 21: Before and after the renovation

TEE KENAK Simulation

Comparisons of different scenarios have been done looking at the results in the energy outputs of the building and the given energy rating scale. Each of these scenarios claims the different options that have been chosen according to the requirements and the regulations of KENAK considering also the economic aspect. The purpose of this study is to evaluate the different outputs of TEE KENAK and how these different options are affected by the retrofitting decisions during the renovation processes. The different output of evaluation allows the inspector to make different decisions considering the energy rating scale as well as the architectural aspects and communicate those to the owners. To keep the modeling process consistent a detailed description on buildings envelope and the existing mechanical systems was been used as an input to the different scenarios.

The study requires calculation on buildings thermal performance to be input on the software. A detailed description of the solid and transparent surfaces of the building is used, considering the U values of the different layers of the wall components, the orientation, the angle, the shading coefficient factor and the external material properties. For the window properties the solar transmittance had to be determined as well as details on the frame percentage and the type of window used.

In order to incorporate the mechanical systems used in the building, a significant number of detailed inputs were required. Considering the available information provided from the residents it was required to determine an over sized efficiency control of the boiler and the air conditioning system. The description of solar panels used represents an effective factor. According to KENAK, the buildings under major renovation require to produce at least 60% of hot water by solar collectors. For that purpose it was necessary to calculate the average monthly load for hot water, the average monthly load covered by the solar panels and the percentage of hot water covered by the solar panels (see Table 18). The sizing of solar panels performance were calculated based on the transient methods for collector performance developed by S.Klein, W.A. Beckman and J.A.Duffie [46]. Considering the results of energy loads covered by solar panels presented in Table 17, the existing solar collectors satisfy only 41% of the building's total need. In fact the solar collectors placed on the roof top of the building serve only three apartments.

Table 17: Zone A water temperature ºC KENAK

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec
13.00	12.80	13.80	16.30	19.90	23.80	26.20	26.60	24.90	21.70	18.10	14.80

Table 18: Solar Panel loads, current situation, Flat plate

Period	Average monthly load for DHW kWh/mo	Average monthly load covered by solar panels kWh/mo	Rate of coverage load by solar panels (%)	Remaining DHW to be covered kWh/mo	Rate of coverage load by different energy sources (%)
January	1598.15	351.94	22.02	1246.21	0.78
February	1451.3	402.90	27.7	1048.40	0.72
March	1563.6	553.92	35.42	1009.68	0.65
April	1408.66	640.13	45.44	768.53	0.55
May	1300.12	668.75	51.43	631.37	0.49
June	1095.16	626.48	57.20	468.68	0.43
July	1028	636.13	61.88	391.87	0.38
August	1010.72	635.18	62.84	375.54	0.37
September	1049.18	617.32	58.83	431.86	0.41
October	1222.37	549.84	44.98	672.53	0.55
November	1333.42	433.82	32.53	899.60	0.67
December	1520.41	340.86	22.41	1179.55	0.78
Total	15581.09	6457.28		9123.81	
Average			0.41		0.59

Given these inputs, the software calculates the results and displays the rating scale of the building including data on the energy consumption. In the second documentation the types of inputs given in the reference building and the different scenarios are summarized. The results list the amount of primary energy, energy consumption and energy needs both for heating, cooling, lighting and hot water based on the inputs provided.

This information can provide a measure to evaluate the performance of the building in the different scenarios. The side by side comparison of the rating scales given in Figure 27, allows comparison of the effects of the different scenarios, evaluation of the optimum energy performance and optimal decision making.

The initial energy calculation of the existing building rates it to the lowest energy rating scale H (see Figure 26). It is evident that high energy consumption can be explained by examining the pour envelope construction and the mechanical system used for heating and cooling the building. The inadequate conditions of the indoor comfort and the low energy performance of the building are related to the energy consumption issues and the design structure strategies used.

Three different scenarios have been used to evaluate how energy performance is related to different decisions. In all three cases the external opaque elements where simulated according to the renovated building.

Scenarios

In the first scenario the aspects of the building envelope components (U values) remained the same as in the existing building. In this stage, the improvement of the active systems used and the addition of solar collectors in order to achieve the desired amount of hot water covered by the solar collectors were considered. Regarding the decisions made, modification in cooling system was utilized, by changing the defaults of the capacity and the performance of the systems. As it was mentioned before, the cooling of the building is almost inexistent since only one room in each floor apartment has an air conditioning devise. In this stage more than one split devices have been placed in each apartment, sized according to the area of each room/zone served. A 9000 BTU 3.5 kW split system was placed in each bedroom, as well as a 24000BTU, 7.9kW unit was used for the dining-living room. In order to achieve the desired amount of domestic hot water covered by the solar panels it was necessary to increase the number of solar collectors. Two additional solar collectors where added in order to achieve the minimum 60% required by the regulations. The first solar collector would serve the apartment in the first floor and the second one would supply hot water to the studio-apartments in the basement floor. Finally, the achieved energy load by solar collectors is 63%.

Table 19: KENAK coverage load >60%, Flat plate

Period	Average monthly load for DHW kWh/mo	Average monthly load covered by solar panels kWh/mo	Rate of coverage load by solar panels (%)	Remaining DHW to be covered kw/mo	Rate of coverage load by different sources of energy (%)
January	1598.15	602.04	37.67	996.11	0.62
February	1451.3	655.48	45.16	795.82	0.55
March	1563.6	871.86	55.75	691.74	0.44
April	1408.66	954.23	67.73	454.43	0.32
May	1300.12	975.89	75.06	324.23	0.25
June	1095.16	901.88	82.35	193.28	0.18
July	1028	950.64	92.47	77.36	0.08
August	1010.72	889.98	88.05	120.74	0.12
September	1049.18	875.15	83.41	174.03	0.17
October	1222.37	839.86	68.70	382.51	0.31
November	1333.42	706.51	52.98	626.91	0.47
December	1520.41	594.91	39.12	925.50	0.61
Total	15581.09	9818.43		5762.66	
Average			0.63		0.37

The initial outputs given from the rating scale were surprising. While air condition systems dramatically affect the electricity consumption during the cooling months and affect the energy performance of the building the information provided by the rating scale result resulted to a higher rating scale. The question generated by these results is the type of evaluation given from the software. It would be controversial adding energy consumption and the results to indicate a higher rating energy scale rather than a lower one. These results claim that climate needs affect the energy consumption.

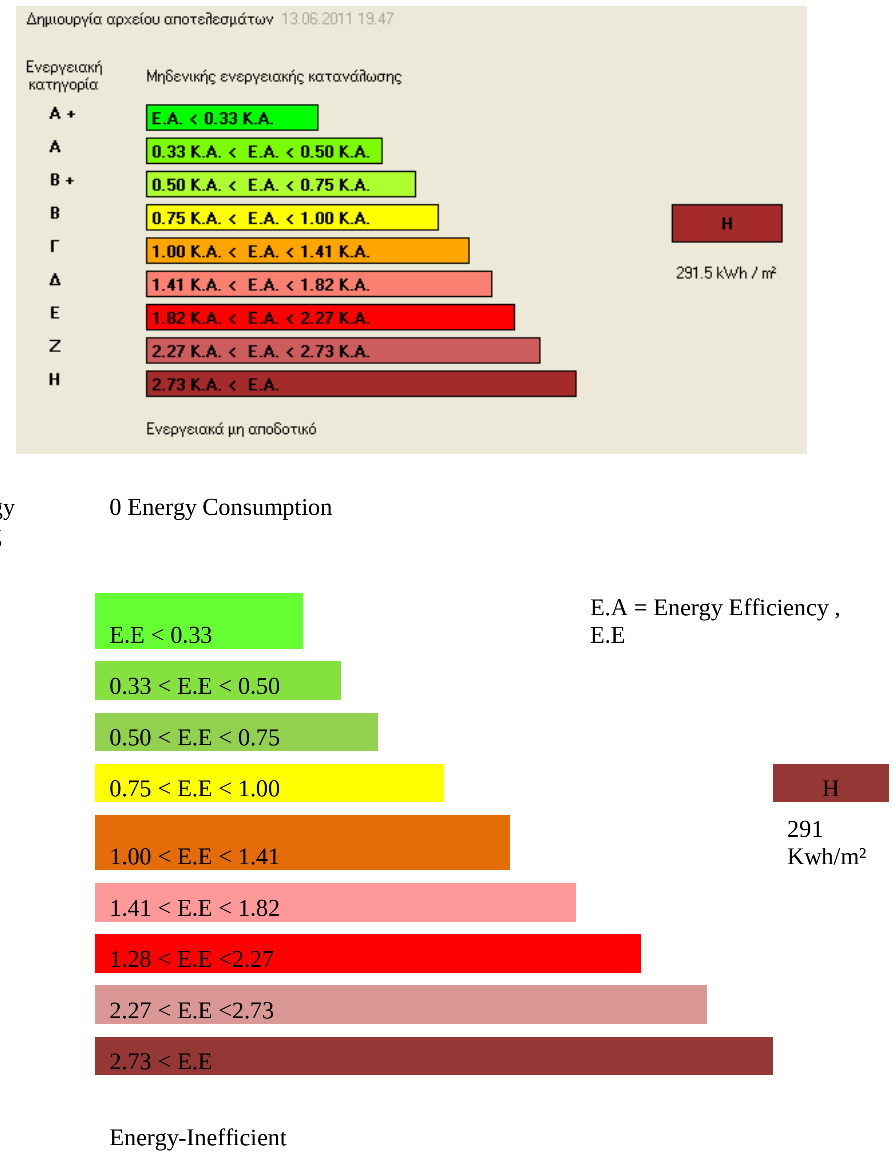


Figure 22: Rating scale, existing building

In the second scenario, factors of building insulation (wall, roof) and energy efficient certified windows were installed according to the maximum requirements of

KENAK (see Table19) and were modeled to see how that affects the energy usage, for instance, to examine whether adding insulation affects the heating and the cooling loads. The parameters of the mechanical systems remained the same. The difference between the existing building and the second scenario modeled was the improvement of the rating scale from H to E. The improvement of the building envelope indicates that insulation is an important attribute on the energy reduction but not that effective since the energy scale was raised by only two levels.

The third scenario is a combination of the first two scenarios. As it was noticed it is impossible to achieve the desired score required for major renovated buildings working only with the improvement of mechanical systems or the envelope retrofitting. In this scenario the goal was to achieve the maximum score possible. A decision like this would also be the most cost effective. As it was mentioned before, an electrical backup system has been used for DHW. In case, the backup system remained the same the score on the rating scale would be B. Only if the backup boilers are connected to the heating oil boiler a B+ score would be achieved.

Πρωτογενής ενέργεια ανα τελική χρήση (kWh/m²)

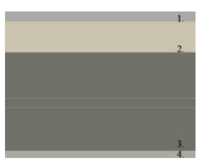
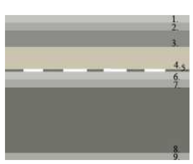
Τελική χρήση	Κτίριο αναφοράς	Υπάρχον κτίριο	Σενάριο 1	Σενάριο 2	Σενάριο 3
Θέρμανση	25.3	102.8	70.2	18.6	12.5
Ψύξη	21.4	121.3	26.5	88.8	21.0
ΖΝΧ	37.2	67.4	50.5	67.4	19.1
Φωτισμός	0.0	0.0	0.0	0.0	0.0
Συνεισφορά ΑΠΕ - ΣΗΘ	0.0	0.0	0.0	0.0	0.0
Σύνολο	83.9	291.5	147.2	174.9	52.7
Κατάταξη	-	Η	Δ	Ε	Β+

Primary energy per usage
(kWh/m²)

Final Consumption	Reference building	Existing Building	Scenario 1	Scenario 2	Scenario 3
Heating	25.3	102.8	70.2	18.6	12.5
Cooling	21	121.3	26.5	88.8	21
DHW	37.2	67.4	50.5	67.4	19.1
Lighting	0	0	0	0	0
Contribution passive systems	0	0	0	0	0
Total	83.9	291.5	147	174.9	52.7
Rating Scale		H	D	E	B+

Figure 23: Primary Energy for different scenarios

Table 20: Existing U values, New U values, maximum U values required by K.E.N.A.K

Element Cross section	Layers		with insulation	maximum requirements K.E.N.A.K	No insulation
		Thickens (m)			
External Wall					
	1.Plaster	0.02			
	2.Insulation	0.075			
	3. Brick	0.08			
	4. Air Gap	0.01			
	5. Brick	0.08			
	6. Plaster	0.01			
External Bean					
	1.Plaster	0.02	U-value	U-value	U-value
	2. Insulation	0.045	(W/m²-k)	(W/m²-k)	(W/m²-k)
	3.Plaster	0.02	0.573	0.6	3.033
	4.Renifored Concrete	0.2			
	5.Plaster	0.01			
External Structural wall					
	1.Plaster	0.02			
	2. Insulation	0.045			
	1.Plaster	0.02			
	2.Renifored Concrete	0.17			
	3.Plaster	0.01			
		Thickens (m)			
Flat Roof					
	1.Tile	0.02			
	2. Plaster	0.02			
	3. Asphalt	0.05	U-value	U-value	U-value
	4. Insulation	0.05	(W/m²-k)	(W/m²-k)	(W/m²-k)
	5. Vapor barrier	0.005	0.499	0.5	3,11
	6. Terrazzo	0.02			
	7. Cement Plaster	0.02			
	8. Concrete Slab	0.2			
	9. Plaster	0.01			

8. CONCLUSIONS

The evaluation of site, climate, age and initial existing conditions are by no means the most important factors affecting the thermal performance of a building. This case study represents only one category of typical residential buildings in Greece. “pilotis”, stores, inexistence of the basement floor, are some of the different options that can be related to the “polykatoikia”[3]. The energy evaluation and improvement of this building type is studied not only by means of improving the active systems but in a broader approach of architectural design decisions to be linked with the needs of the climate and the comfort of the residences.

There are two graphical representations (see Figure 24, 25) in which the energy consumption in (kWh/month) and the Co2 (kg/m²month) emissions are given, resulting from the different scenarios simulated in the “Energy Performance Calculator”. The results given in Figure 24 confirm the considerable energy reduction in scenario two, by adding external insulation and replacing the old windows. The issue of inexistence of thermal insulation and the old type of windows seriously affect the energy performance of the building. Both, exposed structural components and external walls create thermal bridges in the existing building. The low thermal performance during the summer months indicates the need for cooling due to the climate zone needs. The energy consumption before and after the application of thermal insulation and double glazing windows is reduced significantly by approximately 48%.

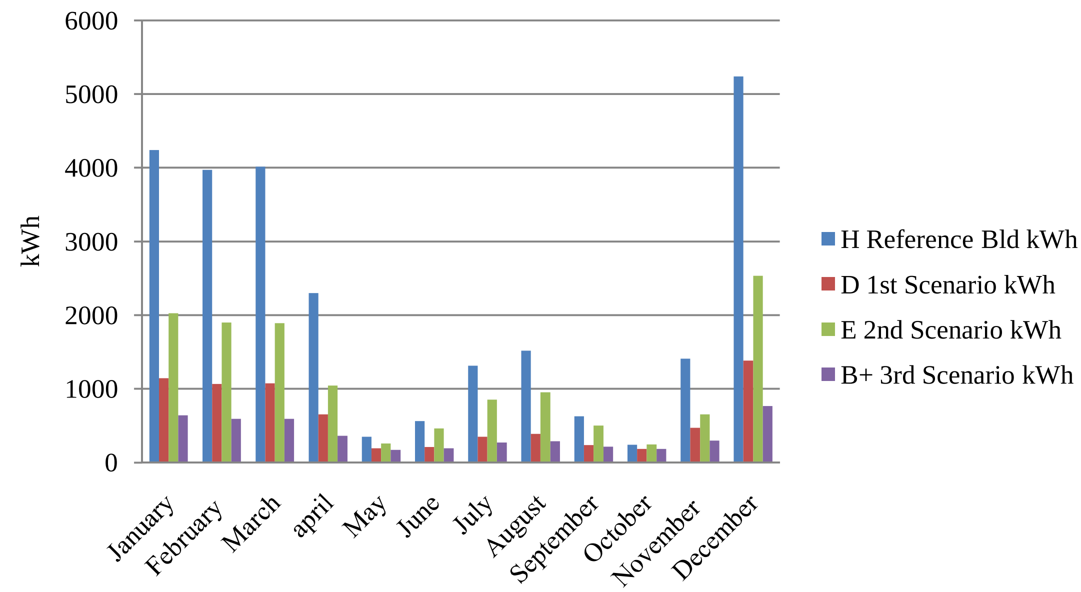


Figure 24: Energy consumption for different scenarios

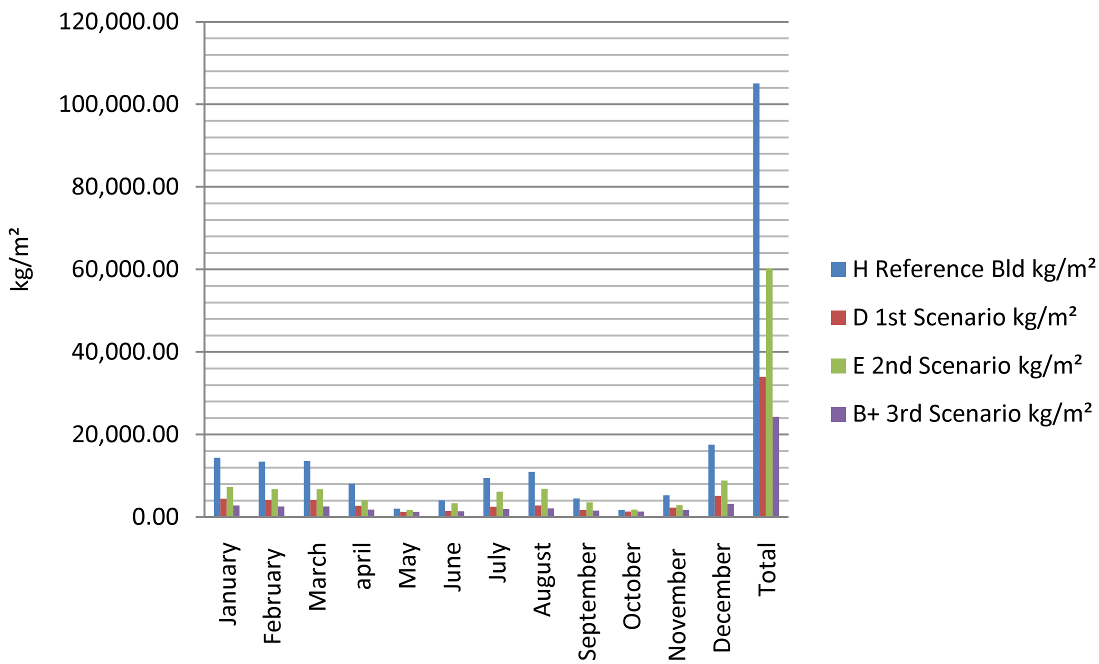


Figure 25: Co2 emission for different scenarios

Even more considerable results can be noticed in the first scenario with an overall energy reduction of 71%. By applying this scenario it was noticed that air conditioning systems can put high energy bills, especially during extremely hot days.

Last but not least, different energy considerations on the impact of the different scenarios on the reduction of the energy consumption can drive to different results. The most effective energy conservation measure with an important energy reduction of 82% is the third scenario. In this case, the new retrofitting operation and the new guidelines reduce significantly the energy demand of the buildings. Design renovation methods along with decision on the mechanical systems used, can lead to the high energy score.

The operation cost and the initial investment payback affect the decisions made. As it is noticed in Table 20, scenario three is the most expensive solution in contrast with the first one which appears to be the less expensive with considerable energy reduction as well. In this case the cost would affect the decision of the owner to accept the proposed retrofitting solution. Comparing the results given in scenario two and scenario three in Table 20 the funds are very close but there is a significant variation in energy.

To understand the worth of implementing the most effective solution in terms of energy and cost savings the affect of time was calculated into the energy analysis by calculating the payback period that takes for the initial investment of each scenario to repay its cost. Cost benefits are most often received as more effective. In this approach it was important to evaluate the energy saving related to financial costs and energy saving of each project. Regarding the Greek statistics, energy cost is equivalent to 0.112925 €/ kWh, where electricity cost represents 0.1139 €/ kWh and heating oil 11.8 €/ L (0.111949 €/ kWh) [32]. In fact the relation between time and energy consumed plotted in the Figure 26 outlines that scenario three has a payback period of forty-six years. It was proven that scenario one would have lower energy saving than scenario three but the payback would be thirty-four years shorter. Considering the investment cost scenario two and scenario three the funds are very close but there is a significant variation in energy consumption. In this case the payback period would be close to seventy-two years with no considerable energy savings.

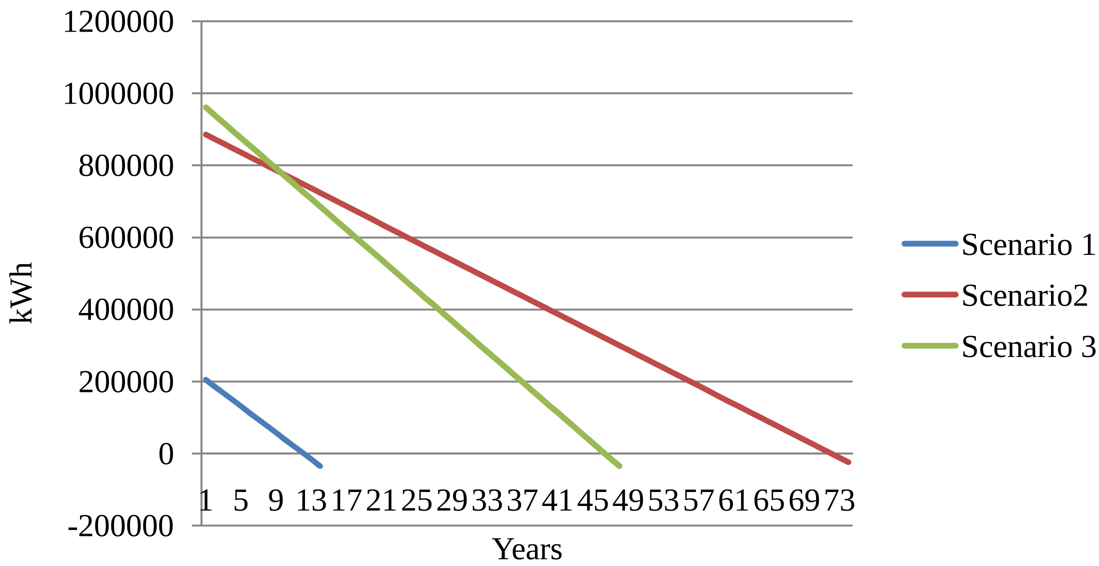


Figure 26: Payback analysis

All the above estimations lead to the conclusion that energy saving benefits given by choosing scenario one as the final solution is the best decision made related to the investment cost and energy saving. Regarding KENAK, scenario three corresponds to the only scenario accepted to achieve the energy rating scale B required for those buildings under major renovation. The responsibility of the inspector has a tremendous affect on the decision made and the energy reductions strategies that should be followed. Obviously the results presented in this project represent only the buildings located in climate zone A. The profession of architect has an important role on designing the building to maintain a low energy consumption evaluating the investment cost. Architectural style characterizes different decades in every county affected by economic issues, climate, and way of living and other parameters as well. The improvement of existing buildings is always an important issue in our communities as the needs of living are changing with drastic rhythms.

The body of this study was to understand the conception of buildings' energy improvement and the strategies that should be followed to transform a typical residential construction in Greece to an energy saving building. Since the certification only started a few months ago it is too early to evaluate and judge the impact of KENAK in Greek building stock. The implementation of the new directive will affect the building construction methods as well the real estate market. Even thought the introduction of EPBD in Greece delayed several years in comparison with other European counties it is a chance to change the methodology of construction in the building sector and improve the buildings energy performance. Qualified energy experts in collaboration with architects and engineers specialized in buildings energy performance should provide advanced architectural solutions related to cost and energy saving that lead to significant results. Buildings energy improvement constitutes a key factor towards the reduction of Co2 emission.

Table 21: Cost evaluation without incentives

Scenario 1

	Cost
Air conditioning 24000BTU 9000BTU	8,000 €
Shading device	5,320 €
External painting	2,000 €
Glass railing	4,500 €
Other	1,500 €
Balconies cutting	2,000 €
Solar collectors	1,900 €
	25,220€

Scenario 2

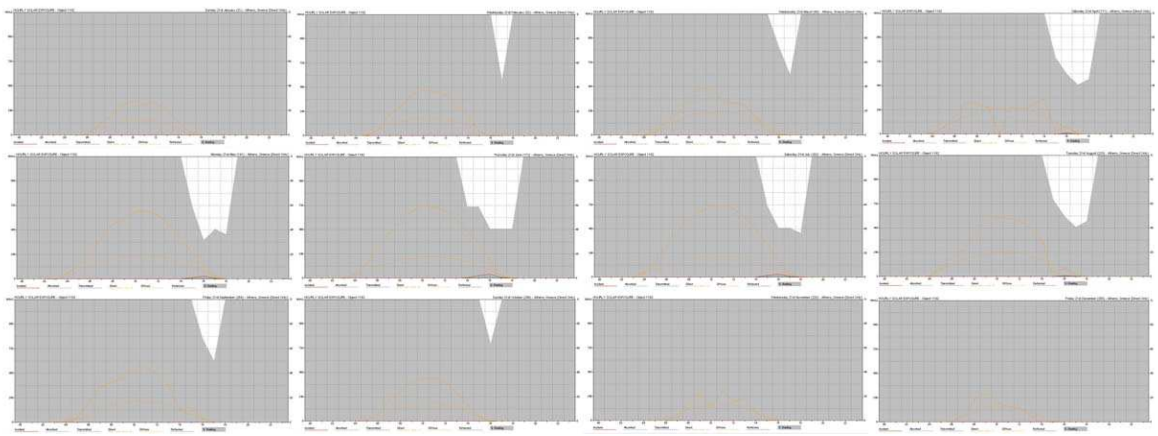
	Cost
Insulation External walls Roof	50,100 €
Low-e windows	35,600 €
Shading device	5,320 €
External painting	2,000 €
Glass railing	4,500 €
Balconies cutting	2,000 €
Solar collectors	1,900 €
	101,420€

Scenario 3

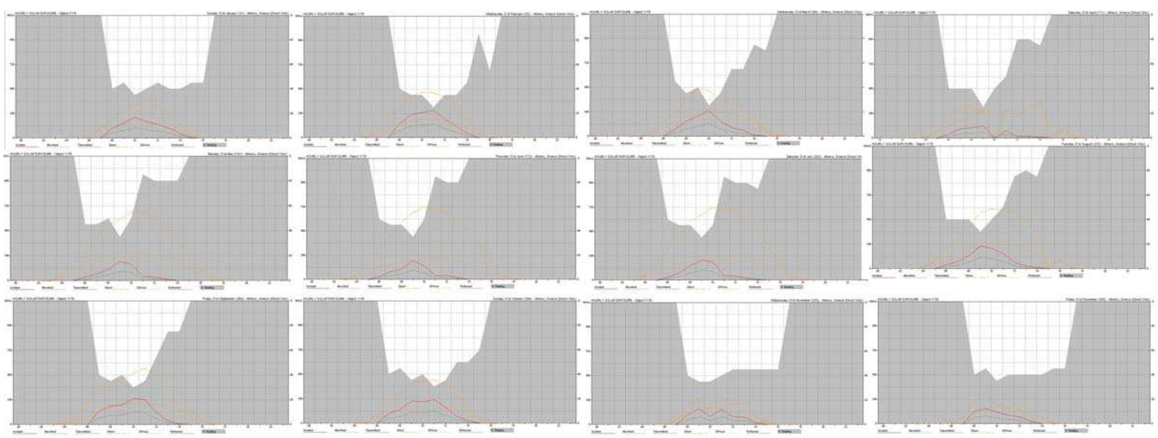
	Cost
Insulation External walls Roof	50,100 €
Low-e windows	35,600 €
Air conditioning 24000BTU 9000BTU	8,000 €
Shading device	5,320 €
External painting	2,000 €
Glass railing	4,500 €
Other	1,500 €
Balconies cutting	2,000 €
Solar collectors	1,900 €
	110,920€

APPENDIX A

Simulation Output, ECOtect



Hourly Solar Exposure NW facade



Hourly Solar Exposure NE(a) facade

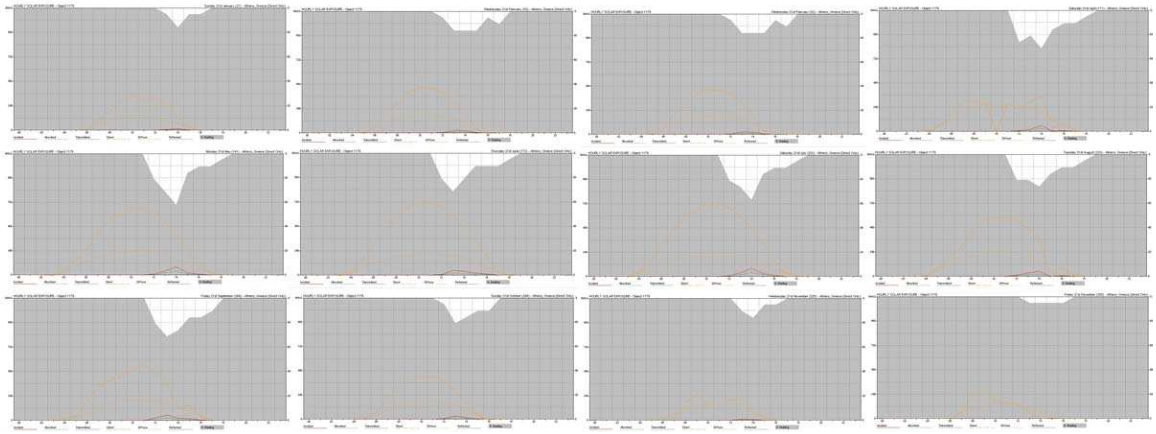
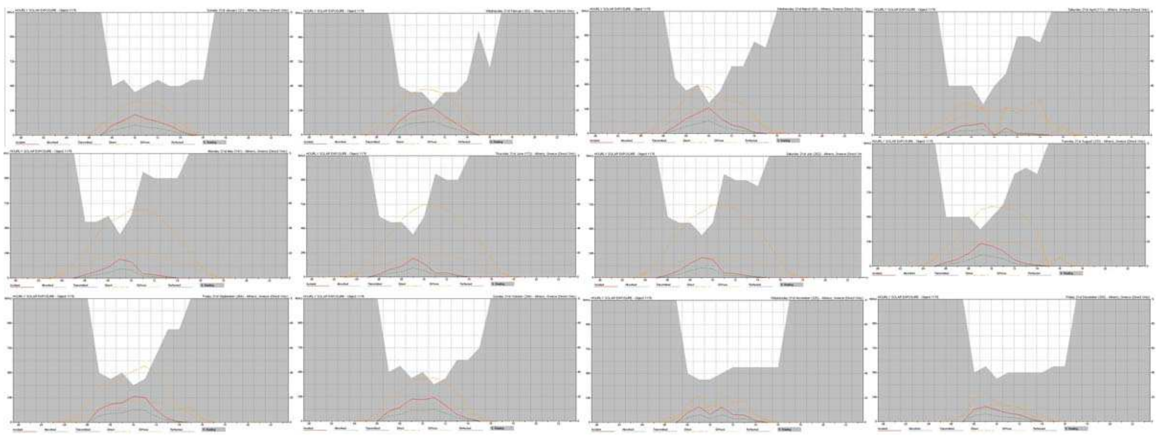
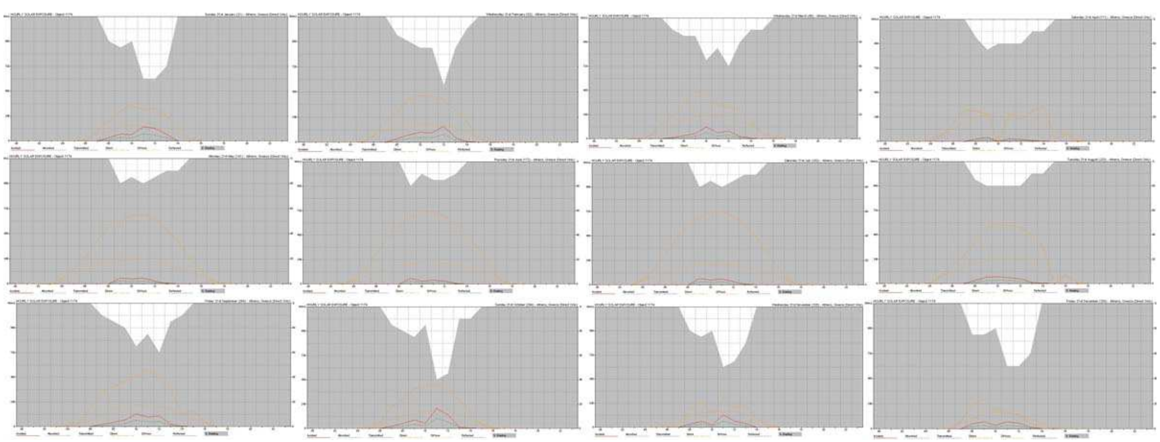


Figure---Hourly Solar Exposure SW facade



Hourly Solar Exposure SE(a) facade



Hourly Solar Exposure SE(b) façade

APPENDIX B

Simulation Output, "Energy Performance Calculator" Exisitng Building

CALCULATION RESULTS

EPC Calculation

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	256	Q_{ref_nd} [kWh/m^2/yr]	151	EPCnd	1.70

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	249	E_{ref_del} [kWh/m^2/yr]	120	EPCdel	2.08

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	418	E_{ref_p} [kWh/m^2/yr]	307	EPCp	1.36

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	105048	$CO2_{ref}$ [g/m2/yr]	62350	EPCco2	1.68

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	180	NOx_{ref} [g/m^2/yr]	110	EPCnox-sox	1.45
SOx_{design} [g/m^2/yr]	340	SOx_{ref} [g/m^2/yr]	270		

Performance Calculation

[E.1] Energy Need Performance

1. Heating Need

Month	$Q_{H,tr}$ [MJ]	$Q_{H,ve}$ [MJ]	$Q_{H,ht}$ [MJ]	$Q_{H,sol}$ [MJ]	$Q_{H,int}$ [MJ]	$Q_{H,gn}$ [MJ]	$\eta_{H,gn}$	$Q_{H,nd}$ [MJ]	$Q_{H,nd}$ [kWh/m2]
Jan	9,539	5,065	14,604	604	1,786	2,390	0.925	12,392	33.21
Feb	9,038	4,799	13,836	801	1,613	2,414	0.920	11,617	31.13
Mar	9,458	5,022	14,480	1,278	1,786	3,064	0.899	11,725	31.42
Apr	6,034	3,204	9,239	1,619	1,728	3,348	0.820	6,493	17.40
May	1,063	565	1,628	1,947	1,786	3,733	0.342	352	0.94
Jun	(4,756)	(2,525)	(7,281)	2,070	1,728	3,799	(1.917)	-	-
Jul	(9,313)	(4,945)	(14,258)	2,073	1,786	3,859	(3.694)	-	-
Aug	(10,683)	(5,672)	(16,355)	1,853	1,786	3,639	(4.495)	-	-
Sep	(5,457)	(2,898)	(8,355)	1,450	1,728	3,178	(2.629)	-	-
Oct	(596)	(317)	(913)	1,068	1,786	2,854	(0.320)	-	-
Nov	3,649	1,937	5,586	698	1,728	2,426	0.785	3,682	9.87
Dec	11,536	6,126	17,662	553	1,786	2,339	0.942	15,459	41.42
Total	49,254	26,154	29,873	16,014	21,028	37,042	N/A	61,718	165.38

[E.1] Energy Need Performance

2. Cooling Need

Month	$Q_{C,tr}$ [MJ]	$Q_{C,ve}$ [MJ]	$Q_{C,ht}$ [MJ]	$Q_{C,sol}$ [MJ]	$Q_{C,int}$ [MJ]	$Q_{C,gn}$ [MJ]	$\eta_{C,ls}$	$Q_{C,nd}$ [MJ]	$Q_{C,nd}$ [kWh/m2]
Jan	14,372	7,409	21,782	604	1,786	2,390	0.105	110	0.29
Feb	13,403	6,910	20,313	801	1,613	2,414	0.113	123	0.33
Mar	14,292	7,368	21,659	1,278	1,786	3,064	0.133	192	0.52
Apr	10,712	5,522	16,235	1,619	1,728	3,348	0.186	327	0.88
May	5,897	3,040	8,937	1,947	1,786	3,733	0.331	773	2.07
Jun	(78)	(40)	(118)	2,070	1,728	3,799	1.000	3,917	10.50
Jul	(4,479)	(2,309)	(6,788)	2,073	1,786	3,859	1.000	10,648	28.53
Aug	(5,849)	(3,015)	(8,864)	1,853	1,786	3,639	1.000	12,503	33.50
Sep	(780)	(402)	(1,182)	1,450	1,728	3,178	1.000	4,360	11.68
Oct	4,238	2,185	6,422	1,068	1,786	2,854	0.347	627	1.68
Nov	8,326	4,292	12,619	698	1,728	2,426	0.175	219	0.59
Dec	16,370	8,439	24,809	553	1,786	2,339	0.091	89	0.24
Total	76,425	39,399	115,824	16,014	21,028	37,042	N/A	33,887	90.80

[E.2] Delivered Energy

Total Amount									
Month	Electricity (Atlanta) ECool [kWh]	Electricity (Atlanta) Elight [kWh]	Electricity (Atlanta) Efan [kWh]	Electricity (Atlanta) Epump [kWh]	Electricity (Atlanta) Eos [kWh]	Electricity (On Site) E. Gen. [kWh]	Fuel Oil (Atlanta) Eheat [kWh]	Electricity (Atlanta) EDHW [kWh]	Net Total Net Cons. [kWh]
Jan	12	135	-	-	56	-	4,038	-	4,241
Feb	14	122	-	-	50	-	3,786	-	3,971
Mar	21	115	-	-	56	-	3,821	-	4,013
Apr	36	93	-	-	54	-	2,116	-	2,299
May	86	96	-	-	56	-	115	-	352
Jun	434	74	-	-	54	-	-	-	562
Jul	1,180	77	-	-	56	-	-	-	1,313
Aug	1,385	77	-	-	56	-	-	-	1,518
Sep	483	93	-	-	54	-	-	-	630
Oct	70	115	-	-	56	-	-	-	241
Nov	24	130	-	-	54	-	1,200	-	1,408
Dec	10	135	-	-	56	-	5,038	-	5,238
Total	3,755	1,262	-	-	658	-	20,113	-	25,788

[E.3] Primary Energy Consumption Performance

Month	$E_{p,total}$ [kWh]	$E_{p,total}$ [kWh/m2]
Jan	5,498	53.2
Feb	5,139	49.7
Mar	5,204	50.3
Apr	3,142	30.4
May	943	9.1
Jun	1,909	18.5
Jul	4,455	43.1
Aug	5,152	49.8
Sep	2,139	20.7
Oct	817	7.9
Nov	2,137	20.7
Dec	6,680	64.6
Total	43,214	418.04

[E.4] CO2 Emissions Performance

Month	$CO2_{design}$ [g/m²]
Jan	14,350.15
Feb	13,420.97
Mar	13,582.85
Apr	8,074.01
May	2,076.12
Jun	4,048.15
Jul	9,446.68
Aug	10,925.87
Sep	4,535.51
Oct	1,732.63
Nov	5,331.15
Dec	17,523.63
Total	105,047.72

APPENDIX C

Simulation Output, "Energy Performance Calculator" Scenario 1

EPC Calculation

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	256	Q_{ref_nd} [kWh/m^2/yr]	151	EPCnd	1.70

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	71	E_{ref_del} [kWh/m^2/yr]	120	EPCdel	0.59

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	141	E_{ref_p} [kWh/m^2/yr]	307	EPCp	0.46

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	33983	$CO2_{ref}$ [g/m2/yr]	62350	EPCco2	0.55

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	59	NOx_{ref} [g/m^2/yr]	110	EPCnox-sox	0.51
SOx_{design} [g/m^2/yr]	128	SOx_{ref} [g/m^2/yr]	270		

Performance Calculation

[E.1] Energy Need Performance

1. Heating Need

Month	$Q_{H,tr}$ [MJ]	$Q_{H,ve}$ [MJ]	$Q_{H,ht}$ [MJ]	$Q_{H,sol}$ [MJ]	$Q_{H,int}$ [MJ]	$Q_{H,gn}$ [MJ]	$\eta_{H,gn}$	$Q_{H,nd}$ [MJ]	$Q_{H,nd}$ [kWh/m2
Jan	9,539	5,065	14,604	604	1,786	2,390	0.925	12,392	33.21
Feb	9,038	4,799	13,836	801	1,613	2,414	0.920	11,617	31.13
Mar	9,458	5,022	14,480	1,278	1,786	3,064	0.899	11,725	31.42
Apr	6,034	3,204	9,239	1,619	1,728	3,348	0.820	6,493	17.40
May	1,063	565	1,628	1,947	1,786	3,733	0.342	352	0.94
Jun	(4,756)	(2,525)	(7,281)	2,070	1,728	3,799	(1.917)	-	-
Jul	(9,313)	(4,945)	(14,258)	2,073	1,786	3,859	(3.694)	-	-
Aug	(10,683)	(5,672)	(16,355)	1,853	1,786	3,639	(4.495)	-	-
Sep	(5,457)	(2,898)	(8,355)	1,450	1,728	3,178	(2.629)	-	-
Oct	(596)	(317)	(913)	1,068	1,786	2,854	(0.320)	-	-
Nov	3,649	1,937	5,586	698	1,728	2,426	0.785	3,682	9.87
Dec	11,536	6,126	17,662	553	1,786	2,339	0.942	15,459	41.42
Total	49,254	26,154	29,873	16,014	21,028	37,042	N/A	61,718	165.38

[E.1] Energy Need Performance

2. Cooling Need

Month	$Q_{C,tr}$ [MJ]	$Q_{C,ve}$ [MJ]	$Q_{C,ht}$ [MJ]	$Q_{C,sol}$ [MJ]	$Q_{C,int}$ [MJ]	$Q_{C,gn}$ [MJ]	$\eta_{C,ls}$	$Q_{C,nd}$ [MJ]	$Q_{C,nd}$ [kWh/m2
Jan	14,372	7,409	21,782	604	1,786	2,390	0.105	110	0.29
Feb	13,403	6,910	20,313	801	1,613	2,414	0.113	123	0.33
Mar	14,292	7,368	21,659	1,278	1,786	3,064	0.133	192	0.52
Apr	10,712	5,522	16,235	1,619	1,728	3,348	0.186	327	0.88
May	5,897	3,040	8,937	1,947	1,786	3,733	0.331	773	2.07
Jun	(78)	(40)	(118)	2,070	1,728	3,799	1.000	3,917	10.50
Jul	(4,479)	(2,309)	(6,788)	2,073	1,786	3,859	1.000	10,648	28.53
Aug	(5,849)	(3,015)	(8,864)	1,853	1,786	3,639	1.000	12,503	33.50
Sep	(780)	(402)	(1,182)	1,450	1,728	3,178	1.000	4,360	11.68
Oct	4,238	2,185	6,422	1,068	1,786	2,854	0.347	627	1.68
Nov	8,326	4,292	12,619	698	1,728	2,426	0.175	219	0.59
Dec	16,370	8,439	24,809	553	1,786	2,339	0.091	89	0.24
Total	76,425	39,399	115,824	16,014	21,028	37,042	N/A	33,887	90.80

[E.2] Delivered Energy

Total Amount									
Month	Electricity (Atlanta) ECool [kWh]	Electricity (Atlanta) Elight [kWh]	Electricity (Atlanta) Efan [kWh]	Electricity (Atlanta) Epump [kWh]	Electricity (Atlanta) Eos [kWh]	Electricity (On Site) E. Gen. [kWh]	Fuel Oil (Atlanta) Eheat [kWh]	Electricity (Atlanta) EDHW [kWh]	Net Total Net Cons.
Jan	2	135	-	-	56	-	954	-	1,146
Feb	3	122	-	-	50	-	894	-	1,068
Mar	4	115	-	-	56	-	902	-	1,077
Apr	7	93	-	-	54	-	500	-	653
May	16	96	-	-	56	-	27	-	195
Jun	80	74	-	-	54	-	-	-	209
Jul	218	77	-	-	56	-	-	-	351
Aug	257	77	-	-	56	-	-	-	389
Sep	89	93	-	-	54	-	-	-	237
Oct	13	115	-	-	56	-	-	-	184
Nov	4	130	-	-	54	-	283	-	472
Dec	2	135	-	-	56	-	1,189	-	1,382
Total	695	1,262	-	-	658	-	4,749	-	7,364

[E.3] Primary Energy Consumption Performance

Month	$E_{p,total}$ [kWh]	$E_{p,total}$ [kWh/m2]
Jan	1,790	17.3
Feb	1,657	16.0
Mar	1,669	16.1
Apr	1,117	10.8
May	602	5.8
Jun	709	6.9
Jul	1,192	11.5
Aug	1,321	12.8
Sep	803	7.8
Oct	625	6.0
Nov	978	9.5
Dec	2,069	20.0
Total	14,532	140.58

[E.4] CO2 Emissions Performance

Month	$CO2_{design}$ [g/m^2]
Jan	4,430.90
Feb	4,109.67
Mar	4,140.68
Apr	2,701.85
May	1,294.52
Jun	1,503.21
Jul	2,528.06
Aug	2,801.98
Sep	1,702.59
Oct	1,325.05
Nov	2,263.23
Dec	5,181.04
Total	33,982.77

APPENDIX D

Simulation Output, "Energy Performance Calculator" Scenario 2

EPC Calculation

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	134	Q_{ref_nd} [kWh/m^2/yr]	151	EPCnd	0.89

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	129	E_{ref_del} [kWh/m^2/yr]	120	EPCdel	1.07

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	248	E_{ref_p} [kWh/m^2/yr]	307	EPCp	0.81

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	60236	$CO2_{ref}$ [g/m2/yr]	62350	EPCco2	0.97

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	105	NOx_{ref} [g/m^2/yr]	110	EPCnox-sox	0.89
SOx_{design} [g/m^2/yr]	222	SOx_{ref} [g/m^2/yr]	270		

[E.1] Energy Need Performance

1. Heating Need

Month	$Q_{H,tr}$ [MJ]	$Q_{H,ve}$ [MJ]	$Q_{H,ht}$ [MJ]	$Q_{H,sol}$ [MJ]	$Q_{H,int}$ [MJ]	$Q_{H,gn}$ [MJ]	$\eta_{H,gn}$	$Q_{H,nd}$ [MJ]	$Q_{H,nd}$ [kWh/m2
Jan	2,470	5,065	7,535	340	1,786	2,126	0.910	5,602	15.01
Feb	2,340	4,799	7,139	468	1,613	2,081	0.905	5,255	14.08
Mar	2,449	5,022	7,472	763	1,786	2,549	0.883	5,220	13.99
Apr	1,563	3,204	4,767	972	1,728	2,701	0.784	2,649	7.10
May	275	565	840	1,172	1,786	2,958	0.258	77	0.21
Jun	(1,232)	(2,525)	(3,757)	1,241	1,728	2,970	(1.265)	-	-
Jul	(2,412)	(4,945)	(7,357)	1,239	1,786	3,025	(2.432)	-	-
Aug	(2,766)	(5,672)	(8,439)	1,098	1,786	2,884	(2.926)	-	-
Sep	(1,413)	(2,898)	(4,311)	849	1,728	2,577	(1.673)	-	-
Oct	(154)	(317)	(471)	621	1,786	2,407	(0.196)	-	-
Nov	945	1,937	2,882	397	1,728	2,125	0.716	1,362	3.65
Dec	2,988	6,126	9,114	308	1,786	2,094	0.932	7,162	19.19
Total	12,755	26,154	15,414	9,468	21,028	30,496	N/A	27,326	73.22

[E.1] Energy Need Performance

2. Cooling Need

Month	$Q_{C,tr}$ [MJ]	$Q_{C,ve}$ [MJ]	$Q_{C,ht}$ [MJ]	$Q_{C,sol}$ [MJ]	$Q_{C,int}$ [MJ]	$Q_{C,gn}$ [MJ]	$\eta_{C,ls}$	$Q_{C,nd}$ [MJ]	$Q_{C,nd}$ [kWh/m2
Jan	3,722	7,409	11,131	340	1,786	2,126	0.181	111	0.30
Feb	3,471	6,910	10,381	468	1,613	2,081	0.189	116	0.31
Mar	3,701	7,368	11,069	763	1,786	2,549	0.215	174	0.47
Apr	2,774	5,522	8,297	972	1,728	2,701	0.290	296	0.79
May	1,527	3,040	4,567	1,172	1,786	2,958	0.486	738	1.98
Jun	(20)	(40)	(60)	1,241	1,728	2,970	1.000	3,030	8.12
Jul	(1,160)	(2,309)	(3,469)	1,239	1,786	3,025	1.000	6,494	17.40
Aug	(1,515)	(3,015)	(4,530)	1,098	1,786	2,884	1.000	7,414	19.87
Sep	(202)	(402)	(604)	849	1,728	2,577	1.000	3,181	8.52
Oct	1,097	2,185	3,282	621	1,786	2,407	0.526	681	1.82
Nov	2,156	4,292	6,449	397	1,728	2,125	0.293	237	0.63
Dec	4,239	8,439	12,679	308	1,786	2,094	0.158	88	0.24
Total	19,792	39,399	59,191	9,468	21,028	30,496	N/A	22,559	60.45

[E.2] Delivered Energy

Total Amount									
Month	Electricity (Atlanta) ECool [kWh]	Electricity (Atlanta) Elight [kWh]	Electricity (Atlanta) Efan [kWh]	Electricity (Atlanta) Epump [kWh]	Electricity (Atlanta) Eos [kWh]	Electricity (On Site) E. Gen. [kWh]	Fuel Oil (Atlanta) Eheat [kWh]	Electricity (Atlanta) EDHW [kWh]	Net Total Net Cons. [kWh]
Jan	12	135	-	-	56	-	1,825	-	2,028
Feb	13	122	-	-	50	-	1,713	-	1,898
Mar	19	115	-	-	56	-	1,701	-	1,892
Apr	33	93	-	-	54	-	863	-	1,043
May	82	96	-	-	56	-	25	-	259
Jun	336	74	-	-	54	-	-	-	464
Jul	720	77	-	-	56	-	-	-	852
Aug	821	77	-	-	56	-	-	-	954
Sep	352	93	-	-	54	-	-	-	500
Oct	75	115	-	-	56	-	-	-	247
Nov	26	130	-	-	54	-	444	-	654
Dec	10	135	-	-	56	-	2,334	-	2,534
Total	2,500	1,262	-	-	658	-	8,905	-	13,325

[E.3] Primary Energy Consumption Performance

Month	$E_{p,total}$ [kWh]	$E_{p,total}$ [kWh/m2]
Jan	2,862	27.7
Feb	2,667	25.8
Mar	2,672	25.9
Apr	1,639	15.9
May	823	8.0
Jun	1,576	15.2
Jul	2,893	28.0
Aug	3,239	31.3
Sep	1,696	16.4
Oct	837	8.1
Nov	1,243	12.0
Dec	3,459	33.5
Total	25,606	247.70

[E.4] CO2 Emissions Performance

Month	$CO2_{design}$ [g/m^2]
Jan	7,286.43
Feb	6,797.98
Mar	6,801.19
Apr	4,050.76
May	1,762.06
Jun	3,341.16
Jul	6,134.12
Aug	6,867.83
Sep	3,595.59
Oct	1,775.48
Nov	2,932.02
Dec	8,891.51
Total	60,236.14

APPENDIX E

Simulation Output, “Energy Performance Calculator” Scenario 2

EPC Calculation

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	139	Q_{ref_nd} [kWh/m^2/yr]	151	EPCnd	0.92

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	44	E_{ref_del} [kWh/m^2/yr]	120	EPCdel	0.37

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	104	E_{ref_p} [kWh/m^2/yr]	307	EPCp	0.34

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	24272	$CO2_{ref}$ [g/m2/yr]	62350	EPCco2	0.39

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	43	NOx_{ref} [g/m^2/yr]	110	EPCnox-sox	0.39
SOx_{design} [g/m^2/yr]	104	SOx_{ref} [g/m^2/yr]	270		

Performance Calculation

[E.1] Energy Need Performance

1. Heating Need

Month	$Q_{H,tr}$ [MJ]	$Q_{H,ve}$ [MJ]	$Q_{H,ht}$ [MJ]	$Q_{H,sol}$ [MJ]	$Q_{H,int}$ [MJ]	$Q_{H,gn}$ [MJ]	$\eta_{H,gn}$	$Q_{H,nd}$ [MJ]	$Q_{H,nd}$ [kWh/m2
Jan	2,748	5,065	7,813	389	1,786	2,175	0.908	5,837	15.64
Feb	2,603	4,799	7,402	530	1,613	2,143	0.903	5,466	14.65
Mar	2,724	5,022	7,747	860	1,786	2,646	0.880	5,419	14.52
Apr	1,738	3,204	4,943	1,087	1,728	2,816	0.779	2,749	7.37
May	306	565	871	1,306	1,786	3,092	0.255	81	0.22
Jun	(1,370)	(2,525)	(3,895)	1,373	1,728	3,101	(1.256)	-	-
Jul	(2,683)	(4,945)	(7,628)	1,368	1,786	3,154	(2.418)	-	-
Aug	(3,077)	(5,672)	(8,750)	1,211	1,786	2,997	(2.919)	-	-
Sep	(1,572)	(2,898)	(4,470)	937	1,728	2,665	(1.677)	-	-
Oct	(172)	(317)	(488)	693	1,786	2,479	(0.197)	-	-
Nov	1,051	1,937	2,989	449	1,728	2,177	0.715	1,432	3.84
Dec	3,323	6,126	9,449	353	1,786	2,139	0.931	7,458	19.98
Total	14,188	26,154	15,982	10,555	21,028	31,584	N/A	28,441	76.21

[E.1] Energy Need Performance

2. Cooling Need

Month	$Q_{C,tr}$ [MJ]	$Q_{C,ve}$ [MJ]	$Q_{C,ht}$ [MJ]	$Q_{C,sol}$ [MJ]	$Q_{C,int}$ [MJ]	$Q_{C,gn}$ [MJ]	$\eta_{C,ls}$	$Q_{C,nd}$ [MJ]	$Q_{C,nd}$ [kWh/m2
Jan	4,140	7,409	11,549	389	1,786	2,175	0.178	115	0.31
Feb	3,861	6,910	10,771	530	1,613	2,143	0.188	123	0.33
Mar	4,117	7,368	11,485	860	1,786	2,646	0.214	187	0.50
Apr	3,086	5,522	8,608	1,087	1,728	2,816	0.290	319	0.86
May	1,699	3,040	4,739	1,306	1,786	3,092	0.486	789	2.11
Jun	(22)	(40)	(63)	1,373	1,728	3,101	1.000	3,164	8.48
Jul	(1,290)	(2,309)	(3,599)	1,368	1,786	3,154	1.000	6,754	18.10
Aug	(1,685)	(3,015)	(4,700)	1,211	1,786	2,997	1.000	7,697	20.62
Sep	(225)	(402)	(627)	937	1,728	2,665	1.000	3,291	8.82
Oct	1,221	2,185	3,405	693	1,786	2,479	0.521	705	1.89
Nov	2,399	4,292	6,691	449	1,728	2,177	0.289	245	0.66
Dec	4,716	8,439	13,155	353	1,786	2,139	0.156	92	0.25
Total	22,015	39,399	61,414	10,555	21,028	31,584	N/A	23,482	62.92

[E.2] Delivered Energy

Total Amount

Month	Electricity (Atlanta) ECool [kWh]	Electricity (Atlanta) Elight [kWh]	Electricity (Atlanta) Efan [kWh]	Electricity (Atlanta) Epump [kWh]	Electricity (Atlanta) Eos [kWh]	Electricity (On Site) E. Gen. [kWh]	Fuel Oil (Atlanta) Eheat [kWh]	Electricity (Atlanta) EDHW [kWh]	Net Total Net Cons. [kWh]
Jan	2	135	-	-	56	-	449	-	642
Feb	3	122	-	-	50	-	421	-	595
Mar	4	115	-	-	56	-	417	-	592
Apr	7	93	-	-	54	-	211	-	365
May	16	96	-	-	56	-	6	-	174
Jun	65	74	-	-	54	-	-	-	193
Jul	139	77	-	-	56	-	-	-	271
Aug	158	77	-	-	56	-	-	-	291
Sep	68	93	-	-	54	-	-	-	215
Oct	14	115	-	-	56	-	-	-	186
Nov	5	130	-	-	54	-	110	-	300
Dec	2	135	-	-	56	-	574	-	766
Total	482	1,262	-	-	658	-	2,188	-	4,590

[E.3] Primary Energy Consumption Performance

Month	$E_{p,total}$ [kWh]	$E_{p,total}$ [kWh/m2]
Jan	1,189	11.5
Feb	1,093	10.6
Mar	1,091	10.6
Apr	773	7.5
May	578	5.6
Jun	656	6.4
Jul	921	8.9
Aug	987	9.5
Sep	728	7.0
Oct	630	6.1
Nov	774	7.5
Dec	1,336	12.9
Total	10,758	104.07

[E.4] CO2 Emissions Performance

Month	$CO2_{design}$ [g/m^2]
Jan	2,821.58
Feb	2,598.97
Mar	2,590.96
Apr	1,781.08
May	1,230.42
Jun	1,392.05
Jul	1,953.02
Aug	2,092.31
Sep	1,544.80
Oct	1,336.59
Nov	1,714.42
Dec	3,216.17
Total	24,272.37

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